# NASA Technical Memorandum 80220

# A CARBON FIBER EXPOSURE TEST FACILITY AND INSTRUMENTATION


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# SUMMARY

A facility has been developed to test electrical and electronic equipment for vulnerability to airborne carbon/graphite fibers. The facility, located at NASA's Langley Research Center, was designed to meet the following objectives:

1. Provide a method of chopping and uniformly dispensing carbon fibers (CF) of selectable lengths and concentrations within a contained controlled test area.

2. Provide the means for determining and recording the real time concentration and exposure of carbon fibers within the test chamber.

3. Provide the facilities through which test articles could be monitored for behavior and/or failure for the duration of exposure.

During the course of the design and fabrication of the facility, simulation, sensing and handling techniques were devised or improved by which the electrical effects of carbon fibers on various types of equipment could be observed and recorded.

# INTRODUCTION

The purpose of this memorandum is to summarize and document the procedures, design and instrumentation associated with the vulnerability exposure test facilities operated under the direction of the Graphite Fibers Risk Analysis Program Office (GFRAPO) at NASA's Langley Research Center. The period of operation was from January of 1978 through March of 1980. The program objectives were twofold:

1. To quantify the risk associated with the accidental release of carbon fibers from crash fires of civil aircraft having composite components.

2. To assess the need for protection of civil aircraft from accidentally released carbon fibers.

These objectives were met, in part, as a result of vulnerability testing of various civil and general aviation avionics, consumer products and generic electrical/electronic components using the described facilities.

## Background

<u>Fiber electrical effects</u>.- Carbon-based fibers (i.e., graphite or carbon fibers) have very high strength and stiffness which makes them a desirable component of composite materials. These composites are being applied in such products as sporting goods, automobiles, aircraft (civil and military) and spacecraft. They are, however, highly conductive and when freely released

around electrical or electronic equipment may cause malfunctions and damage. These problems have been encountered and successfully dealt with by fiber manufacturers but until recently had not been considered as a general hazard to other sectors.

Fiber exposure relationships.- Describing the vulnerability of electrical and electronic equipment to carbon fibers requires the definition of the following terms:

1. C - concentration - the density of carbon fibers expressed in fibers per cubic meter.

2. E - exposure - the time integration of concentration expressed in fiber-seconds per cubic meter.

$$E = \int C dt \left(\frac{\text{f-sec}}{m^3}\right)$$

3. D - deposition - surface accumulation expressed in fibers per square meter $(f/m^2)$.

We can relate exposure to deposition on vertical surfaces using horizontal air velocity and on horizontal surfaces using fiber vertical fall velocity.

$$E = D/v$$

where

$D$ = deposition in $f/m^2$

$V$ = velocity in m/sec

## Fiber Selection for Test

Length.- Vulnerability exposure testing in laboratory facilities, such as described herein, has been done with virgin carbon fibers chopped to specific lengths depending on the type of equipment in question. Outdoor electrical power equipment, for instance, would be more vulnerable to long (greater than 10 mm) fibers since contact spacings are normally large to withstand physical and environmental effects. Indoor electrical equipment however would be vulnerable to shorter lengths as well. In fact, the manner in which the equipment is enclosed will strongly determine its maximum vulnerable length (i.e., size of ventilating or access openings). For this reason most of the GFRAPO testing has been with fiber lengths between 1 and 15 millimeters.

Fiber type.- Experience has shown that some fibers are more easily handled than others. Celanese GY-70, used extensively by the USAF Rome Air Development Center (RADC), Rome, New York, for instance, was found to be easily chopped and

aspirated by the relatively simple means described later. These fibers, about 8 to 12 microns in diameter, are supplied in small bundles (tows) of approximately 400 fibers each. The fall rate was found to be not significantly different (within about 50 percent) from most others commonly used by composite manufacturers.

Fibers used most commonly, however, are more typically represented by Union Carbide's T-300 for electrical and mechanical characteristics. These 8 micron diameter fibers are supplied in tows of about 3,000 each and have a higher tendency to cohere and be dispensed as clumps rather than single fibers. The bulk resistance of this fiber, however, is almost a factor of two higher than GY-70. While fiber resistivity differences in power circuits (where arcing and/or burnout occurs) have little effect on associated failures, those differences might be significant in electronics where small currents control larger currents. For this reason, it was decided to deal with the more difficult handling properties of the T-300 and use it for the majority of testing.

### Test Article Selection

The GFRAPO employed several government and industrial agencies, under contract, as sources of information on equipment from which test items were selected. These organizations included airframe manufacturers, Department of Defense agencies, industrial research groups and the Department of Commerce.

The following classes of equipment were selected for testing:

1. Avionics components and systems

2. Consumer, commercial and industrial equipment

3. Power distribution terminals at voltages up to 440 VAC

4. Generic electrical and electronic component parts

Candidate classes of equipment were analyzed for criticality of personal or public safety and commercial, industrial and consumer economic impact. The components of item 4 above were selected by examining items 1, 2 and 3 for generics from which separate exposure testing might result in a better understanding of equipment classes. For example, a variety of special exposure tests were run on motors, connectors, relays and printed circuits (refs. 1 and 2).

## EXPOSURE FACILITY AND INSTRUMENTATION

Our first experiments with carbon fibers were conducted to identify the electrical and mechanical properties of carbon fibers and understand their effect on energized electrical fixtures and appliances. Individual fibers of known length were examined for bulk resistivity, contact effects, burnout current and energy (ref. 2).

## Small Test Chamber

The small chamber of figure 1 was designed for initial exposure testing of energized components. Constructed of plywood, it served as a means of exposing various small motors, receptacles and power contact configurations. A known quantity of pre-cut fibers was admitted to the chamber and maintained in circulation by small fans and external agitators until the desired exposure was reached. While sufficient for these crude experiments, the uncertainties of concentration and distribution were determined unacceptable for further program testing. The small test chamber experiment did, however, suggest requirements for a facility which would better serve the program objectives.

## Main Test Chamber

Based on experience with the small test chamber, the following requirements were established for a facility to serve the program test objectives:

1. Use a principal mode of operation employing free fall of fibers in relatively undisturbed air with provisions for conversion to turbulent or forced flow for special tests.

2. Provide uniform distribution of free falling fibers over the largest known test articles.

3. Provide a means for chopping fibers of selected lengths and uniformly dispensing them at varying rates over the area of interest.

4. Provide ease of access and cleaning.

5. Prevent or control fiber contamination of adjacent areas and equipment.

A survey of existing exposure facilities was made at several Department of Defense installations and the one best fulfilling the above requirements was found at the RADC, Griffiss Air Force Base, Rome, New York. Their facility consisted of two 3 meter (10 ft.) cube rooms flanking a common control anteroom which contained all fiber handling, chopping and dispensing apparatus. Each chamber was fed by two identical chopper/aspirators driven by common electronics. Entry is made through the access room and a window opens to the instrumentation area outside the chamber complex (ref. 3).

A cut-away illustration of the Langley Research Center main test chamber, which was patterned after the RADC design, is shown in figure 2. A plan view is shown in figure 3. The 3 meter height was kept to maintain the free fall capability and encourage uniform fiber distribution over a volume which might enclose a household washer or dryer, the largest units scheduled for testing. Floor size was reduced to 2.4 meters (8 ft.) square. The wall between the chamber and anteroom was used for the access door and the chopper/aspirator mounting and entry. The aspirator penetration was centered on the wall at about 18 inches from the chamber ceiling. Two fan-shaped baffles, figure 4, were sometimes needed to distribute fibers more uniformly within the chamber.

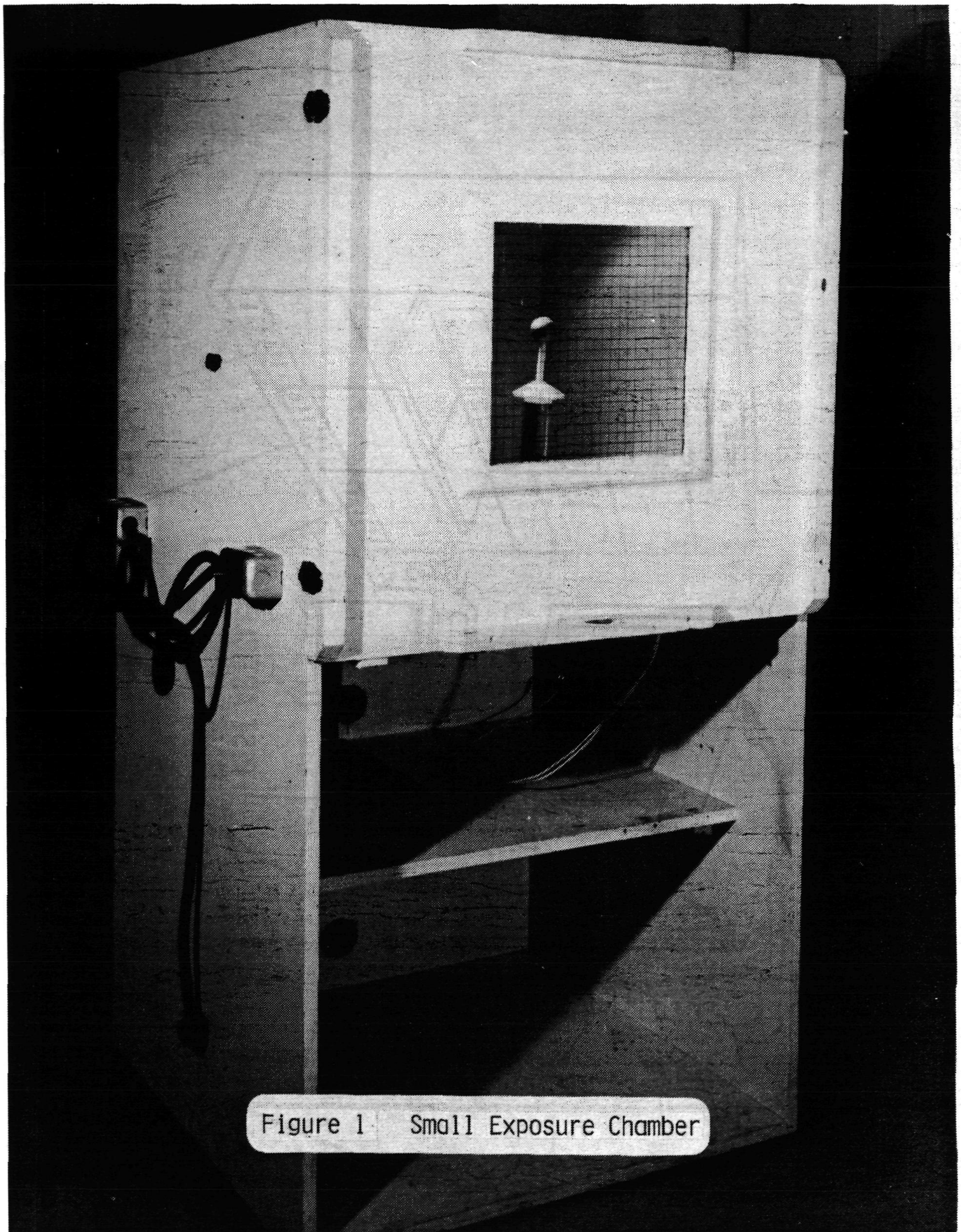

Figure 1 Small Exposure Chamber

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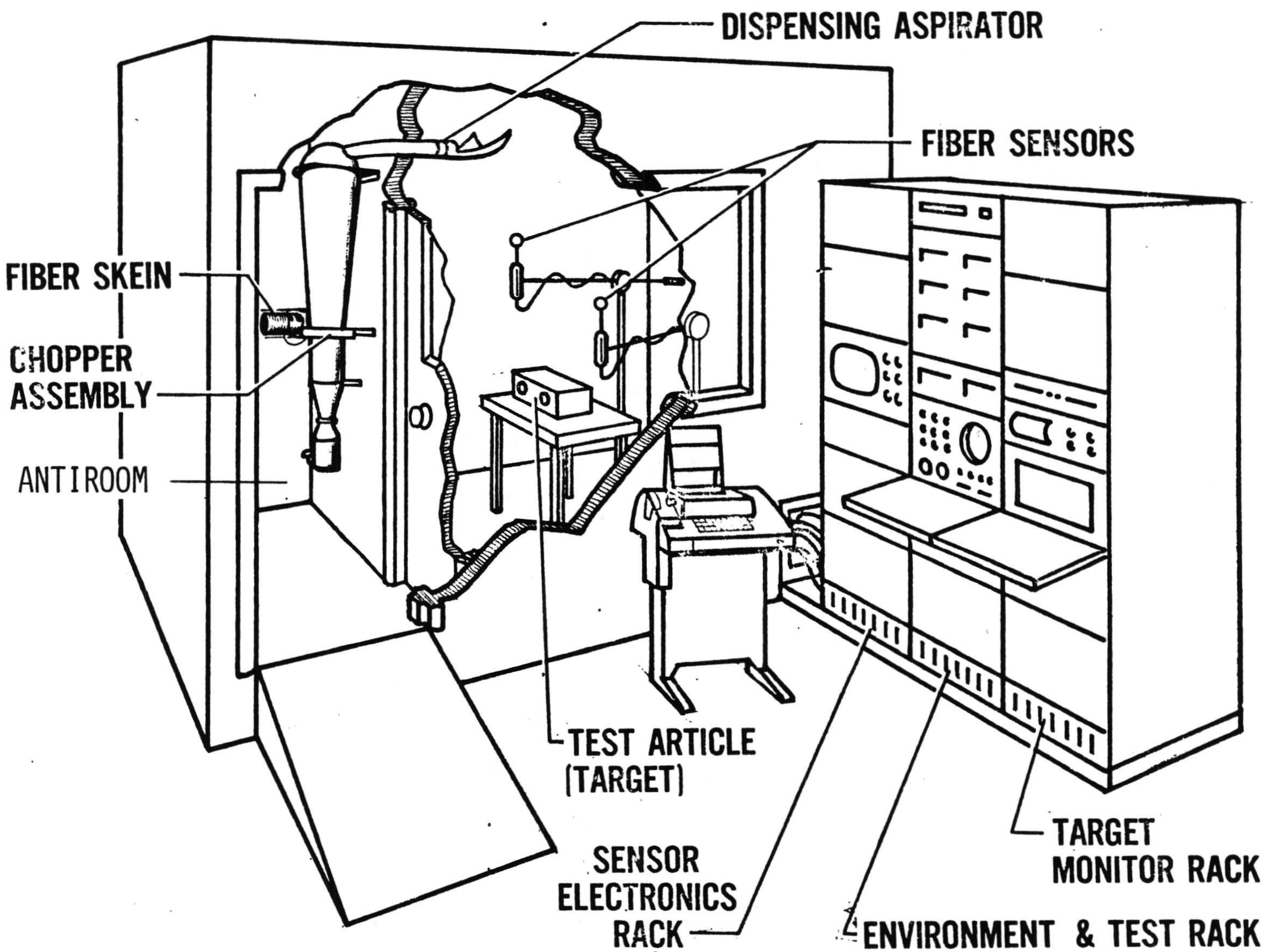


Figure 2 Main Test Chamber - Cutaway

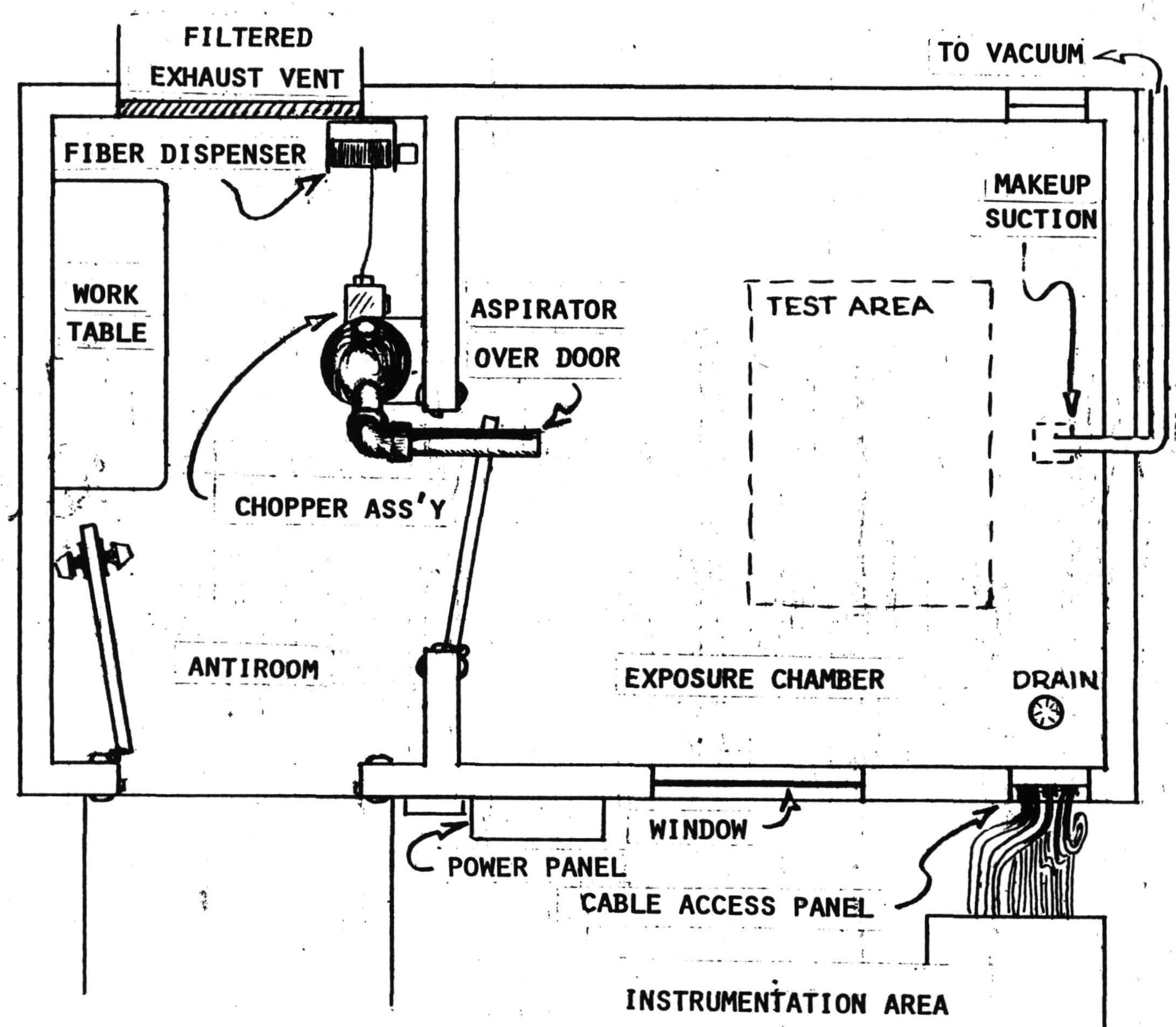


Figure 3 Main Test Chamber - Plan View

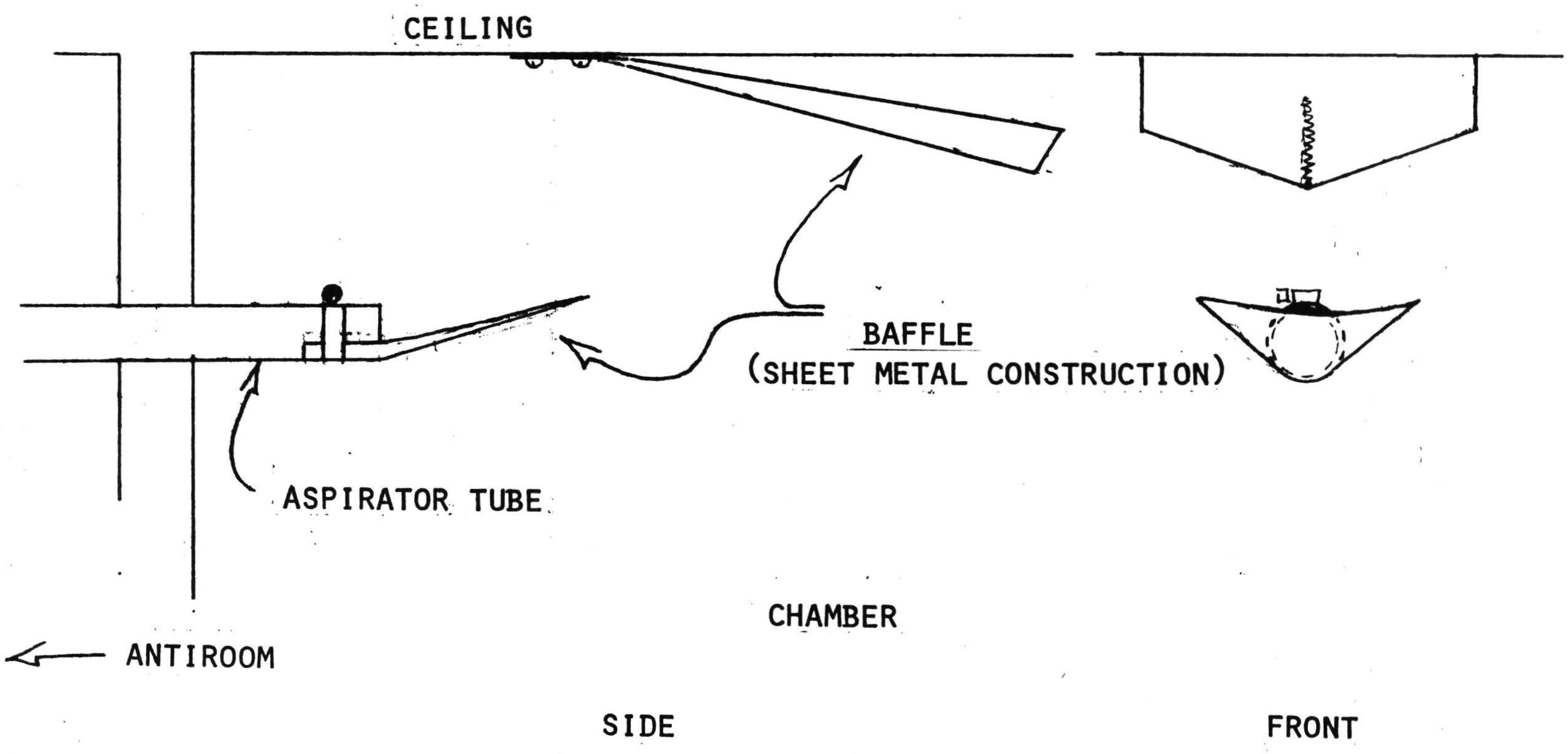


Figure 4 Aspirator Entry Baffles

On the opposite wall, also centrally located, was a suction tube used to compensate for air supplied during aspiration.

The anteroom housed the chopper/aspirator assembly and a small work surface. For decontamination purposes, this room was kept at a slightly negative pressure by a doubly filtered exhaust system. The 30 by 90 centimeters exhaust opening was located near the floor on the wall opposite the outside entry door. Located in the entry door was a large, filtered, pressure equalizing vent to the instrumentation area.

Chamber construction was conventional housing code studding with tempered hardboard glued to the inner walls, then sealed and painted with a white epoxy paint. Exterior walls were covered with conventional dry wallboard. A drain was installed as shown in the chamber floor, should a post-test wash down be required. Flourescent lighting fixtures were flush mounted in the ceiling with switches mounted outside the main entry in the instrumentation area. Convenience outlets were located in the anteroom only. Power and instrumentation access to the chamber are made via either of two removable/replaceable penetration panels located as shown.

Chopper/chimney assembly.- The chopper/chimney assembly is shown in figure 5. It consisted of the fiber dispenser, chopper assembly and chimney coupled to the aspirator at the top. A blast of air may be directed, as needed, at the newly chopped bundle to disperse the fibers in the rising column of air. Air velocity decreases along the expanding cross section of the conical chimney thereby limiting the rise of heavier fiber clumps to the exit port area. The aspirator was a 7.6 centimeter (3 inch) inside diameter annular flow ejector (fig. 6) to provide gentle handling of the fibers. The air source was dried service air regulated and valve controlled to the levels needed. Compensating suction was provided by a shop vacuum cleaner with a speed control. Neutral chamber relative pressure was monitored by an externally mounted manometer. Aspirator operation was monitored with a manometer connected to the chimney assembly. Chimney operating pressures were typically on the order of 3 millimeter (1/10 inch) of water below atmospheric.

Chopper.- Initial chamber operation incorporated a chopper originally designed for the RADC by the MITRE Corporation. The mechanical unit was fabricated at Langley Research Center using the RADC unit as a model and an in-house designed electronic supply. Experience with this unit resulted in a radical design change to improve resolution and speed (fig. 7). It consists of a mechanical assembly including a fixed blade, a moving blade operated by two solenoids (one on each side), a precision indexing motor drive and suitable fixtures to thread, handle and guide the filaments to the chopping blade assembly. Note the fixed blade is nearest the filament supply. The device also includes a digital logic drive electronics assembly which provides the necessary motor indexing, solenoid actuating pulses, appropriate dwell times and air blast modulation (as necessary), each being independently adjustable. Adjustments for rate and length are on the front panel, along with stop/start controls and indicators (ref. 4).

The drive motor meters from 1 to 15 millimeter lengths of multifilament tow according to electronic settings. After waiting an appropriate time for motion

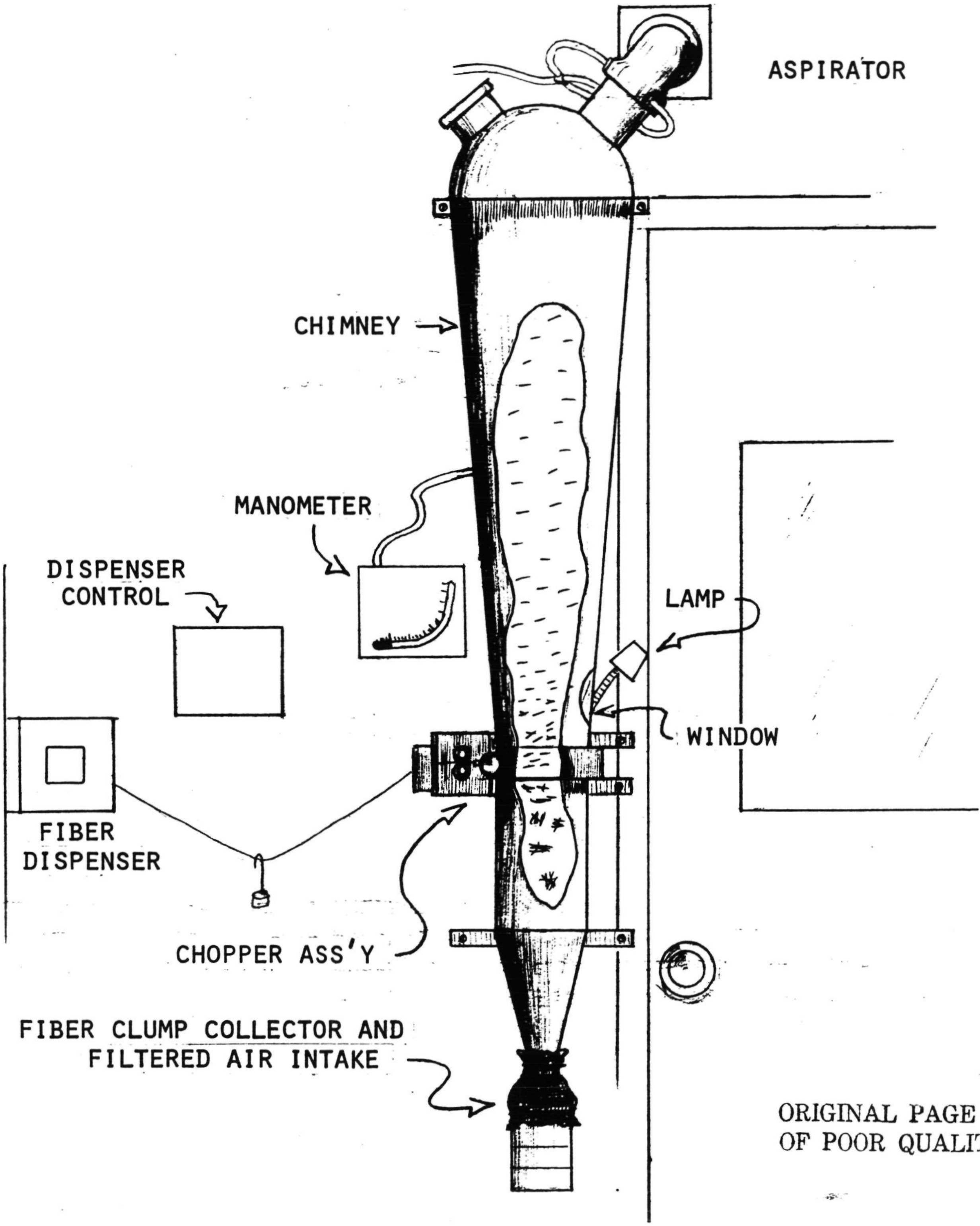


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Figure 5 Chopper/Chimney Assembly

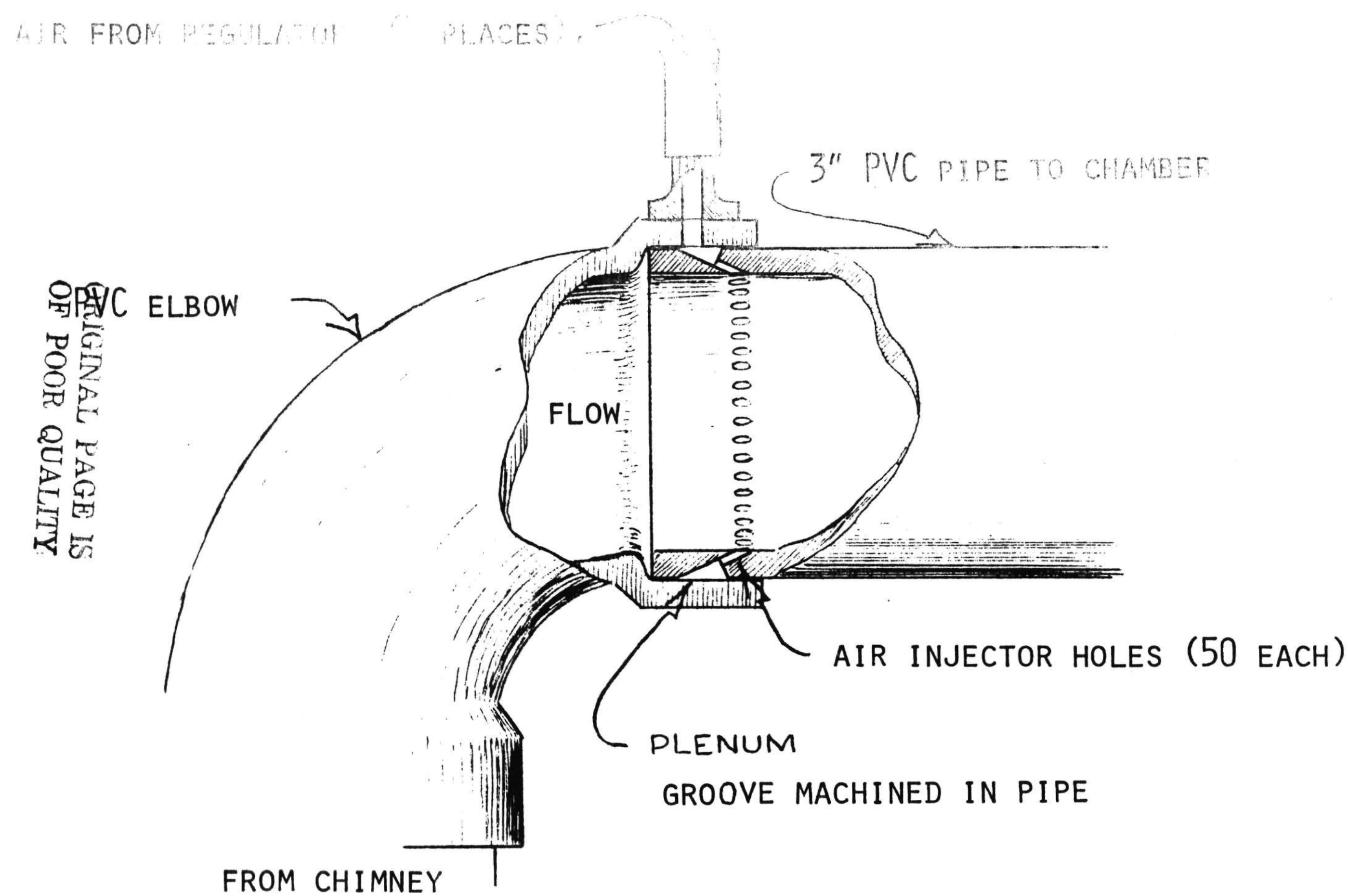


Figure 6 Annular Flow Ejector

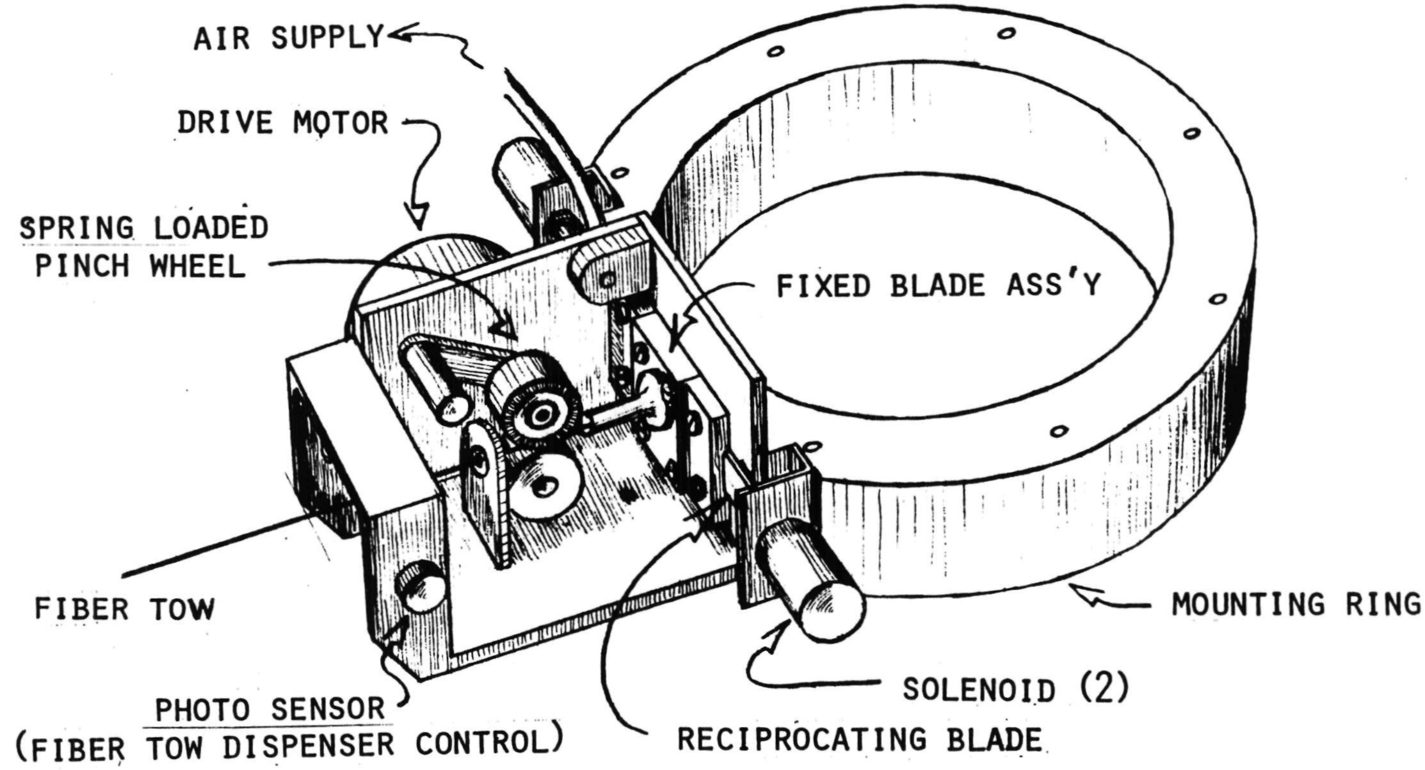


Figure 7 Chopper Assembly

to stop. the proper solenoid is actuated chopping the tow and positioning the other cutting edge for the next chop. At this time a pulse is available to actuate an air blast if necessary for dispensing. Another waiting period, for motions to cease, precedes the next motor operation. As many as 30 chops per second of 10 millimeter fibers can be accommodated by the system.

A simple photocell detector interrupted by the taut fiber tow actuates a motor driven spooling device for the fiber tow supply. A small weighted hook, seen in figure 5, insures proper operation.

Performance.- Chopper performance is such that 90 percent of the fibers chopped are within about 5 percent of the length selected. Fibers below the selected length are probably caused more by breakage in handling than by faulty chopper operation. Fibers longer than selected must be attributed to intermittents in metering drive or improper threading of the mechanism. Figure 8 shows a summary of performance data taken shortly after installation in June of 1979.

Carbon fibers seem to have a propensity to cling to any known surface including the aluminum chimney, PVC pipe, as well as the chamber walls and floor. While this problem is not unique to the Langley Research Center facility, we had hoped that by minimizing oily residue and static charge buildup we would substantially reduce the problem. No significant improvement can be claimed, however, and each test has always included a cleaning of all exposed surfaces, particularly when changing to a different fiber length.

Fiber distribution within the chamber was successfully controlled to keep deviations in fiber deposition to below a factor of two within the 2 square meter test area located just beyond the center of the chamber flow (shown in fig. 3).

## FIBER DETECTOR INSTRUMENTATION

Fiber detectors which might be considered for use in the laboratory are here divided into two primary categories; passive and active. Following is a description of the types of sensors used in the chamber. It should be noted that this is not a comprehensive review of sensing devices. The sensors covered here are only those found applicable to GFRAPO needs.

### Passive

This group of sensors, figure 9, includes those classes of devices which capture fiber samples for later examination for count and length under a microscope. These devices, with the exception of sticky cylinders, measure deposition only. They are inexpensive, require little or no attention during a test but require considerable amounts of labor and time for data retrieval.

Bridal veil.- One of the more accurate and reliable of the passive sensors was developed by the U. S. Army, Dugway Proving Ground (ref. 5). One configuration consists of an open cylinder the size of a tuna can (both ends are removed) with a nylon mesh stretched over and attached to one end. The mesh, whose openings are typically 1 millimeter square (some as small as 1/3 mm), is

| Chopper Setting | % ACTUAL FIBERS AT | | | | | |
|---|---|---|---|---|---|---|
| | <1mm | 1-2mm | 3mm | 4-6mm | 6-10mm | >10mm |
| 1mm | 91 | 5 | 1 | 0 | 0 | 3 |
| 3mm | 1 | 6 | 87 | 6 | 0 | 0 |
| 10mm | 1 | 2 | 2 | 1 | 92 | 1 |

Figure 8 Chopper Performance

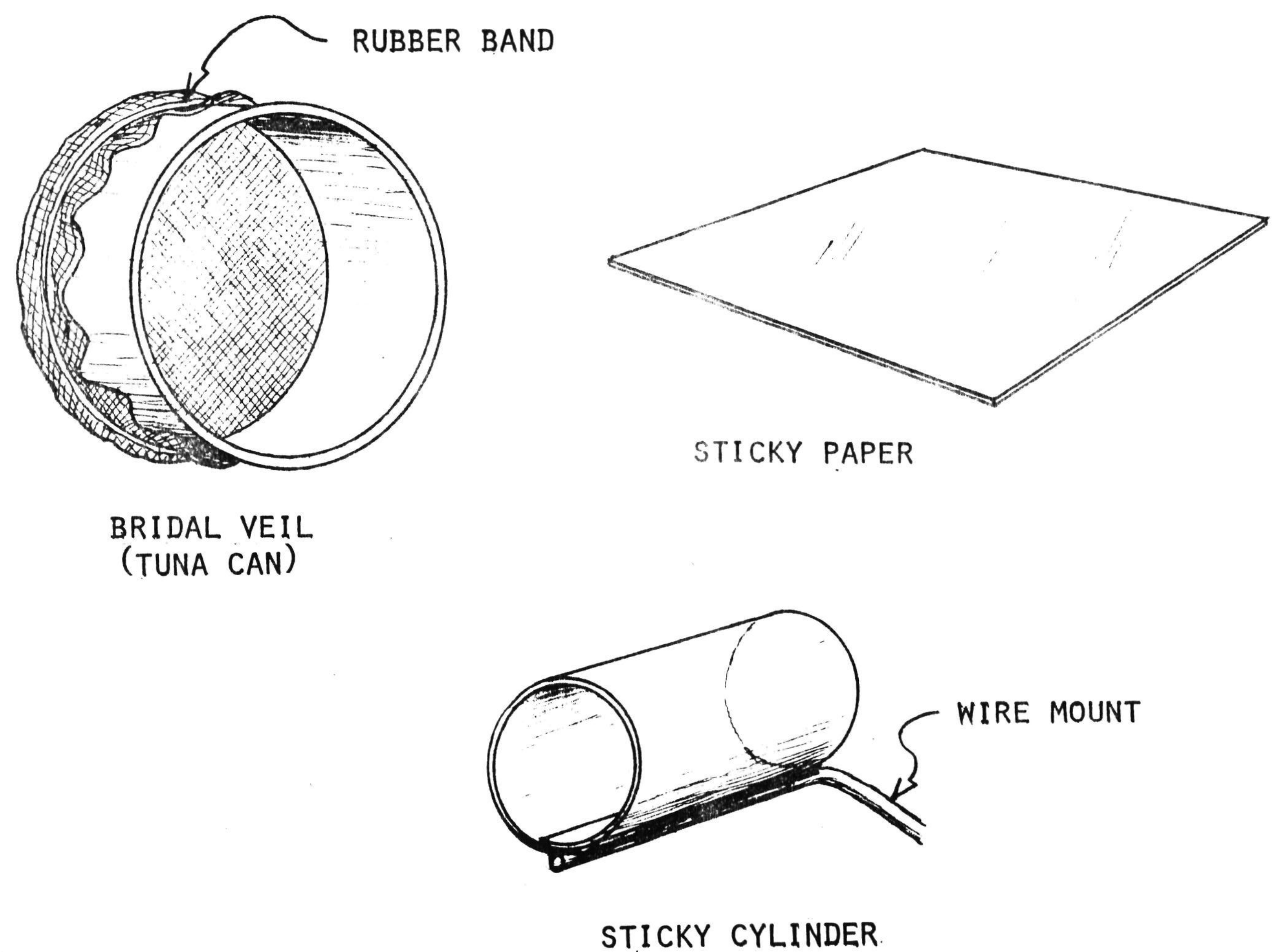


Figure 9 Passive Fiber Collectors

coated with a light oil to provide stickiness. It is a favored standard for calibration for the following reasons:

1. It collects almost all fibers carried by the air passing through, larger than the opening size.

2. It offers the least aerodynamic restriction of all the passive sensors.

For these reasons almost all sensors, active or passive, have been calibrated using some form of "bridal veil" technique.

Sticky paper.- Flat 35 millimeter squares of an adhesive coated clear plastic film are another form of passive measurement in widespread use. They are simply placed on the horizontal surface of interest to record deposition. In the Langley Research Center facility these have been used to verify the uniformity of chopper operation and aspiration within the active area of the test chamber.

Sticky cylinders.- These are made of a 35 millimeter square of sticky paper or clear plastic rolled into a cylinder, sticky side out, and mounted in the area of interest. They are frequently mounted on wire holders by the adhesive as shown. These may be located in almost any environment in the test area, including inside the enclosure of the test article to determine fiber penetration and distribution. They have frequently been used to take contamination samples in the facility instrumentation area, shop, office and in manufacturing areas where CF incidents have been recorded or suspected.

Sticky cylinders are more useful in these applications because their geometry provides sensitivity in all directions orthogonal to the curl axis and due to the cylindrical configuration, its collection properties are not constant with air velocity. In fact, they tend to measure exposure since collection efficiency reduces with increasing air velocity (ref. 2). Sampling in all three axes may be accomplished by mounting two cylinders mutually perpendicular in the same area of interest.

Note that both "bridal veil" and cylinders tend to remove fibers from the test, therefore, care may be required not to starve the test article in areas of high interest.

## Active Sensors

Active sensing devices considered for the exposure facility included mechanical collectors, electrostatic sensors and destructive types (or zappers). While generally more expensive than non-active devices and requiring operating personnel during testing, active sensors deliver data which are much more easily handled.

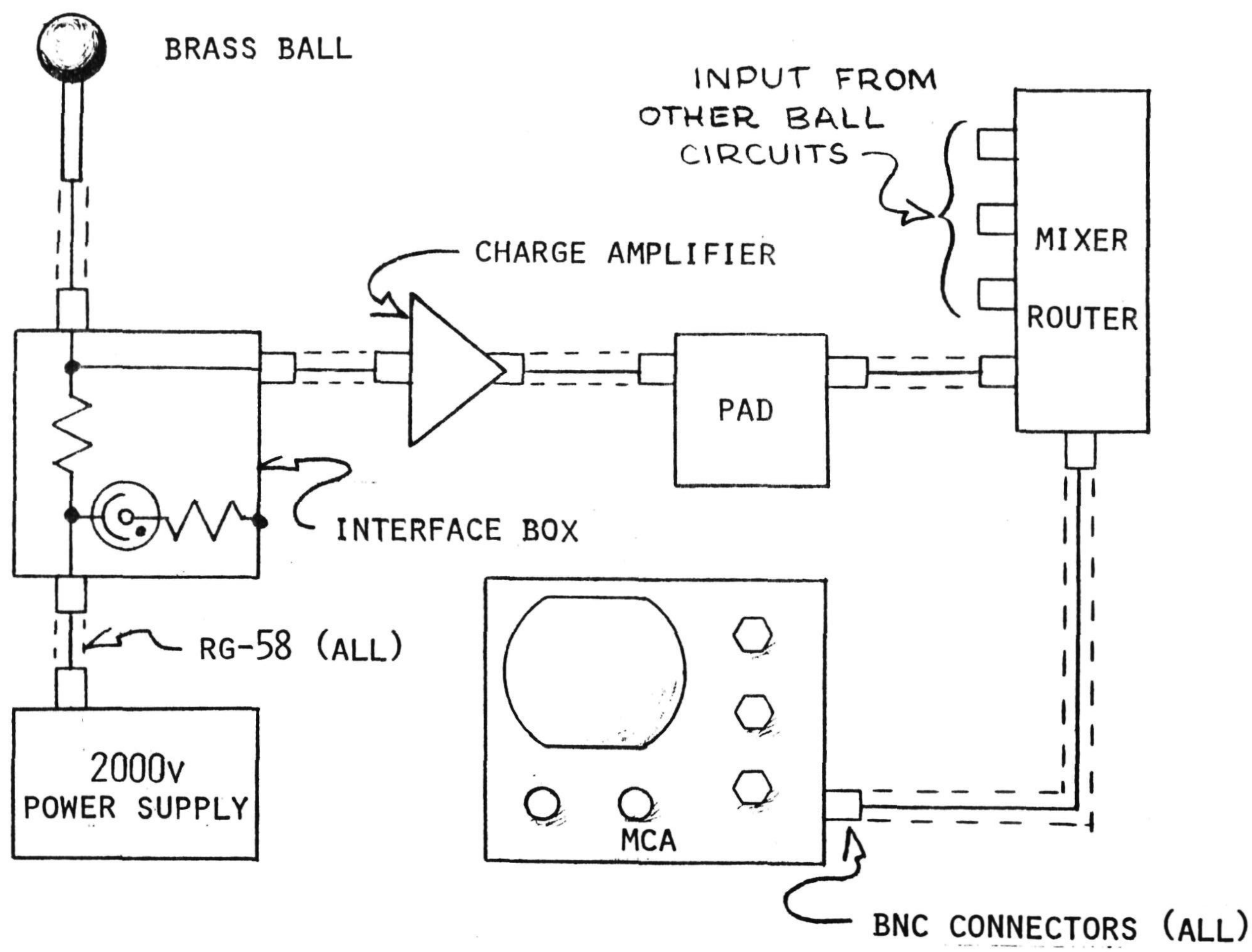


Figure 10 Brass Ball Detector System

Electrostatic.-

Brass Ball Detector: The Brass Ball Detector, developed at the Ballistics Research Laboratory (BRL), Aberdeen, Maryland, (ref. 6), is an electrostatic charge transfer design which allows counting of near field conductive fibers of high aspect ratio in the 3 to 15 millimeter length range. The sensor itself is a rather simple 2.3 centimeter (1-1/2 inch) diameter metal (conductive) ball which is charged to 2 kilovolts. A charge preamp is capacitively coupled and fed to a standard nuclear counting Multi-Channel Analyzer (MCA) through a Preamp/Amp/Discriminator (PAD). The BRL configuration for the sensor is shown in figure 10.

The MCA shown here is a Canberra Series 30 model which is basically a 2048 channel storage device with timing, partitioning, display and interface capabilities. It can be operated in two basic modes, Pulse Height Analysis (PHA) and Multichannel Scaling (MCS).

In the PHA mode input pulses are counted according to pulse height. All pulses of full-scale voltage will be counted and stored in channel 2048; half full scale voltage pulses are counted and stored in channel 1024, etc. In this manner, the unit will display a spectrum of input pulse heights from zero to full scale in a bar graph format. A cursor functions as a means to digitally display on the screen the number of counts in any channel, or group of channels, as well as the total in all channels.

In the MCS mode, the unit simply counts all pulses (regardless of height) within the adjustment range and stores them in succeeding channels. The count, or dwell, time for each channel is selectable. In this manner a time history of pulse events is displayed in bar graph format. Since individual tests are usually run with fibers of a fixed pre-determined length, this is the principal mode of test operation.

The PAD unit provides low-level amplitude discrimination of the input pulses. Using the mixer router, the MCA memory may be partitioned to count pulses from 1, 2 or 4 sensor inputs. The MCA data can be recorded in either or both of two ways which are as follows:

1. A teletype numerical printout of the count in each channel, within the region of interest, selected by the MCA cursor.

2. A cassette recording of the entire memory which can be reread back into the MCA, after the fact, for redisplay and examination.

The Brass Ball functions as follows: Fibers falling within the electrostatic field become charged dipoles and are attracted to the ball. On touching the ball, transfer of charge takes place which is proportional to the capacity represented by the free fiber with respect to that of the ball. The charged fiber is then repelled and resumes its fall in the vicinity of the original path.

When the charge transfer takes place, the voltage at the ball drops proportionally. The nearly instantaneous voltage change is passed by the

charge amplifier to the PAD where it is converted to an output pulse whose rise time is proportional to pulse height. It is then routed to the MCA for counting and/or sorting. The rather complex formula which determines the voltage of the pulse can be simplified since the only variable of interest, and fortunately of significance, is fiber length (ref. 2). This formula is:

$$V_p = kL^x$$

where: $V_p$ = pulse height in volts

$k$ = system constant

$L$ = fiber length

$x$ = appropriate exponent

Using the original formula and empirical data, the values of $k$ and $x$ were determined to be 1.53 and 2.52, respectively, for fiber lengths between 3 and 12 millimeters. For test purposes, however, a fiber length to voltage nomograph was developed for use by operations personnel from a series of tests using actual fibers of known length.

For purposes of calibration and potential improvement of the brass ball a special downflow test chamber was constructed as shown in figure 11. Means were provided to introduce fibers gently to the test section where an anemometer, the ball and a bridal veil sampler were mounted. Fan speed would be set to control air flow.

In each test fibers of known length were introduced at the top of the chamber as shown. The main air inlet at the top of the test section allowed us to vary test velocities independent of fiber introduction. Bridal veil samples were taken, while the ball count, using the MCA, and air velocity were recorded.

The primary purpose of a counting device for the facility was to determine exposure (E). The best way to measure E is with a volume sampling device, that is, a device which samples the same volume per unit time regardless of air velocity. Fortunately, the ball has this property in that its volume sampling variability is a relatively weak function of air velocity. Figure 12 shows test data for two fiber lengths at varying velocities (ref. 2).

During the test and calibration phase, we found that when the RG58 coaxial cable was stressed to 2 kilovolts it became an objectionable noise source subject to any movement including vibration and sound. Also found were noise sources associated with any sharp or pointed terminations on the high voltage components, connectors, etc. In addition, the charge amplifier had a large amount of low frequency noise caused by internal power supply decoupling.

The pulse which results from the charge transfer between ball and fiber has an extremely fast rise time and the input impedance of the charge

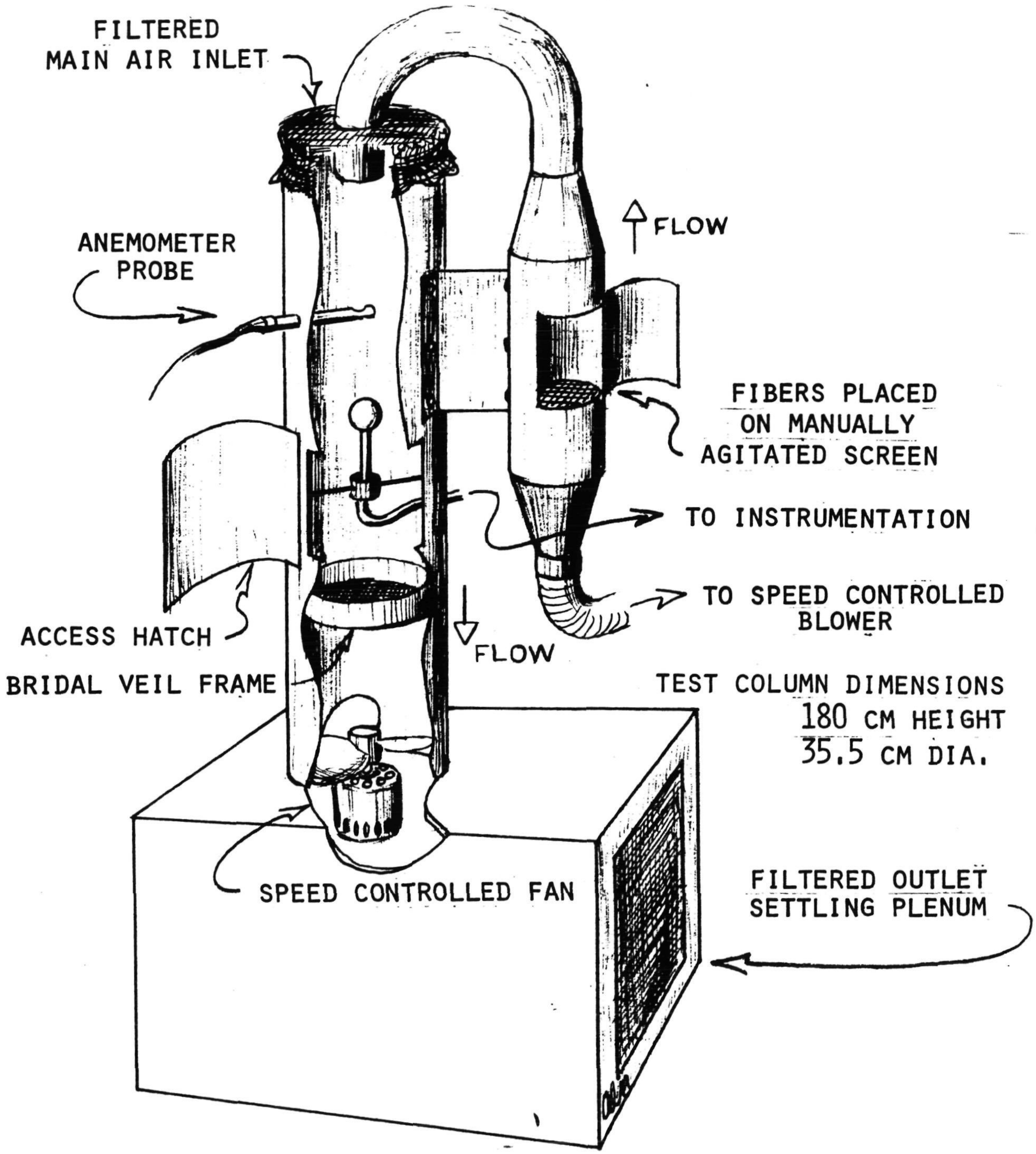


FIGURE 11 DOWNFLOW TEST CHAMBER

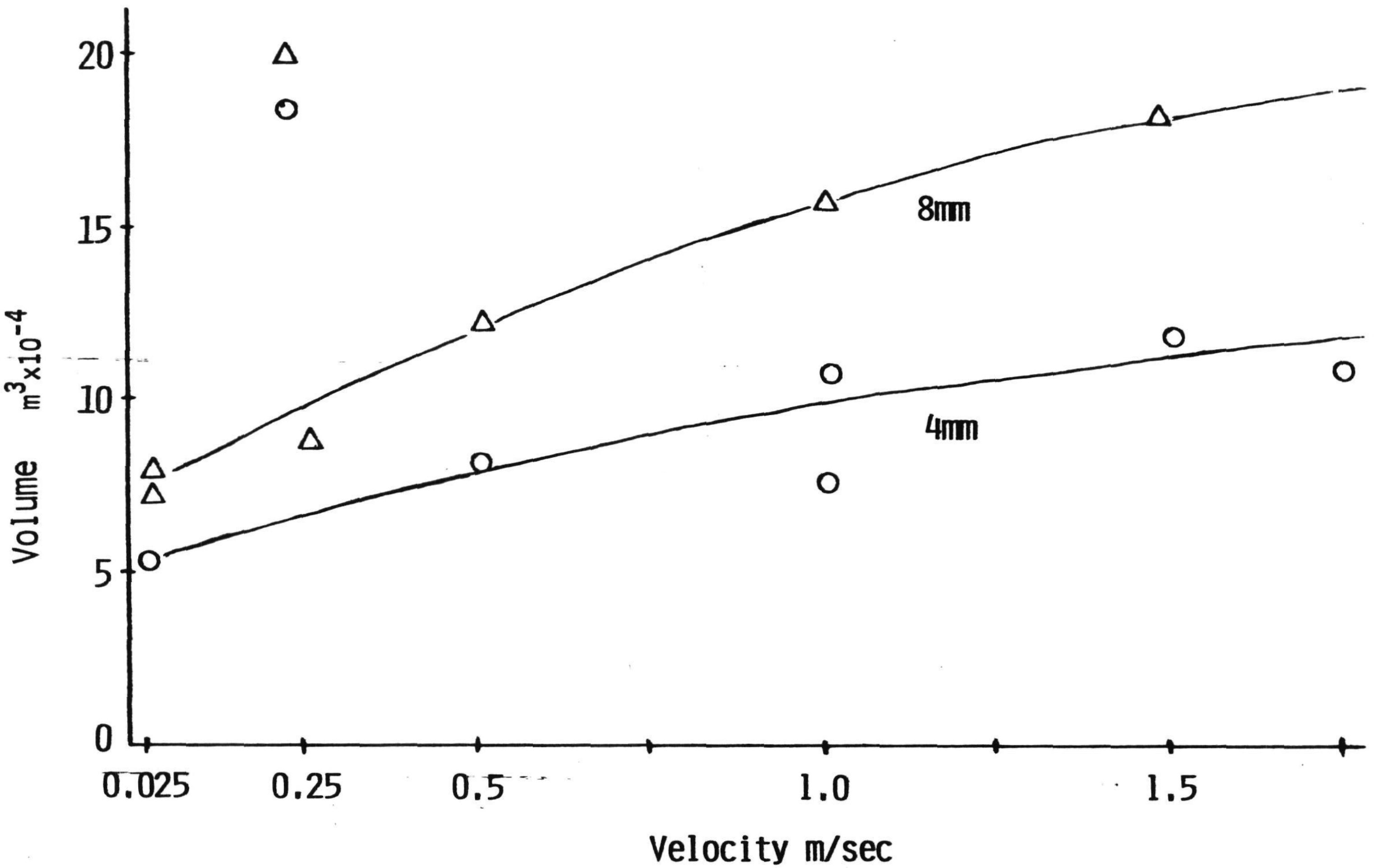


Figure 12 Brass Ball Volume Sampled $\overline{vs}$ Air Velocity

amplifier is 22 megohms. These conditions together with the relatively high shunt capacitance of the input coax, about 28pF per linear foot, have an attenuating effect on the actual amplitude available for measurement.

In order to solve some of these problems, a redesign of the Ball/Preamp configuration was undertaken. The final result is shown in figure 13. The essentials of the ball, the interface minibox and preamplifier, seen in figure 10, were combined. The ball, now made of aluminum, is placed on a slimmer 3/8-inch diameter sting about 3 inches long. Mounted below the sting is the preamp and high voltage interface inside a metal case. The case is fitted with a microphone stand (5/8-27 thread) female bushing. The power supply and output connectors exit from the bottom.

The interface details of the preamplifier are essentially identical to the one used by BRL except that an FET input operational amplifier was used to replace discrete components (fig. 14). The op-amp has a very good slew rate and, by a quirk of internal design, it has almost no rise time limit (in the negative direction) over the voltage range of interest. The high voltage input is bypassed with a 0.01 microfarad capacitor to virtually eliminate the cable noise from the power supply. Testing indicated that the bare wire going up to the sting to the ball was also a source of noise due to the relatively rough nature of the drilled hole. This was minimized by sliding a close fitting plastic sleeve over the wire.

As a result of the redesign, an increase in sensitivity was achieved which allowed the reduction of the high voltage supply to 1,500 volts. This reduced the high tension effects. Further voltage reductions were tried but resulted in significant loss in the effective collecting aperture. All of the calibration effort discussed here used the 1,500 volt supply voltage.

When using the ball in relatively low frequency noise fields (which is most of the time), a cylindrical shield 8 to 10 inches in diameter is placed round the ball during free-fall fiber testing. Under certain conditions it was found that using two ball sensor assemblies, in conjunction with a high speed differential amplifier, could significantly reduce induced noise. Figure 15 shows the circuit. An absolute value circuit on the output makes it possible to take data from either or both sensors. However, since calibration of fiber exposure/concentration is based on one sensor per input to the MCA, high voltage is withheld from the second sensor so that counts from only one are taken. Frequently, the second ball is covered to eliminate any fiber contact. This method of data collection is designed to ignore noise sources inducing equal amplitude and phase (common mode) signals. An anti-coincidence switch on the mixer/router performs a similar function when used near inpulse noise sources. Pulses, occurring within a few nanoseconds, from any two or more inputs are not passed on to the MCA. These techniques permit the ball sensor to count fibers down to about 2 millimeters in relatively noisy electrical environments.

Special electronics were designed and assembled to use a ball sensor in remote or unattended applications. It consists of a low-level discriminator preamp, high voltage supply, LED counter and printer (fig. 16). The discriminator is set to eliminate low-level noise counts and the unit simply counts

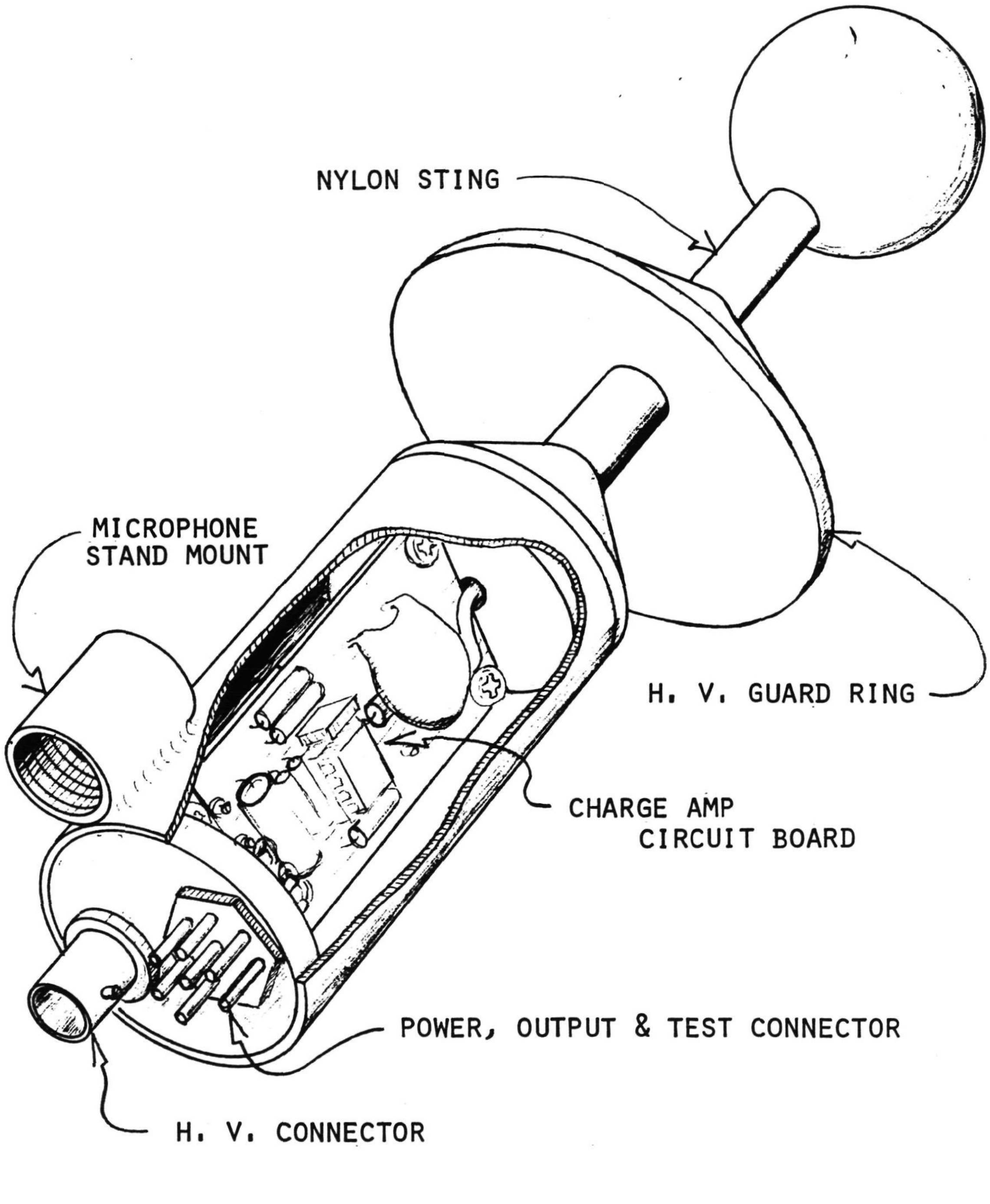


FIGURE 13 FINAL BRASS BALL/PREAMP CONFIGURATION

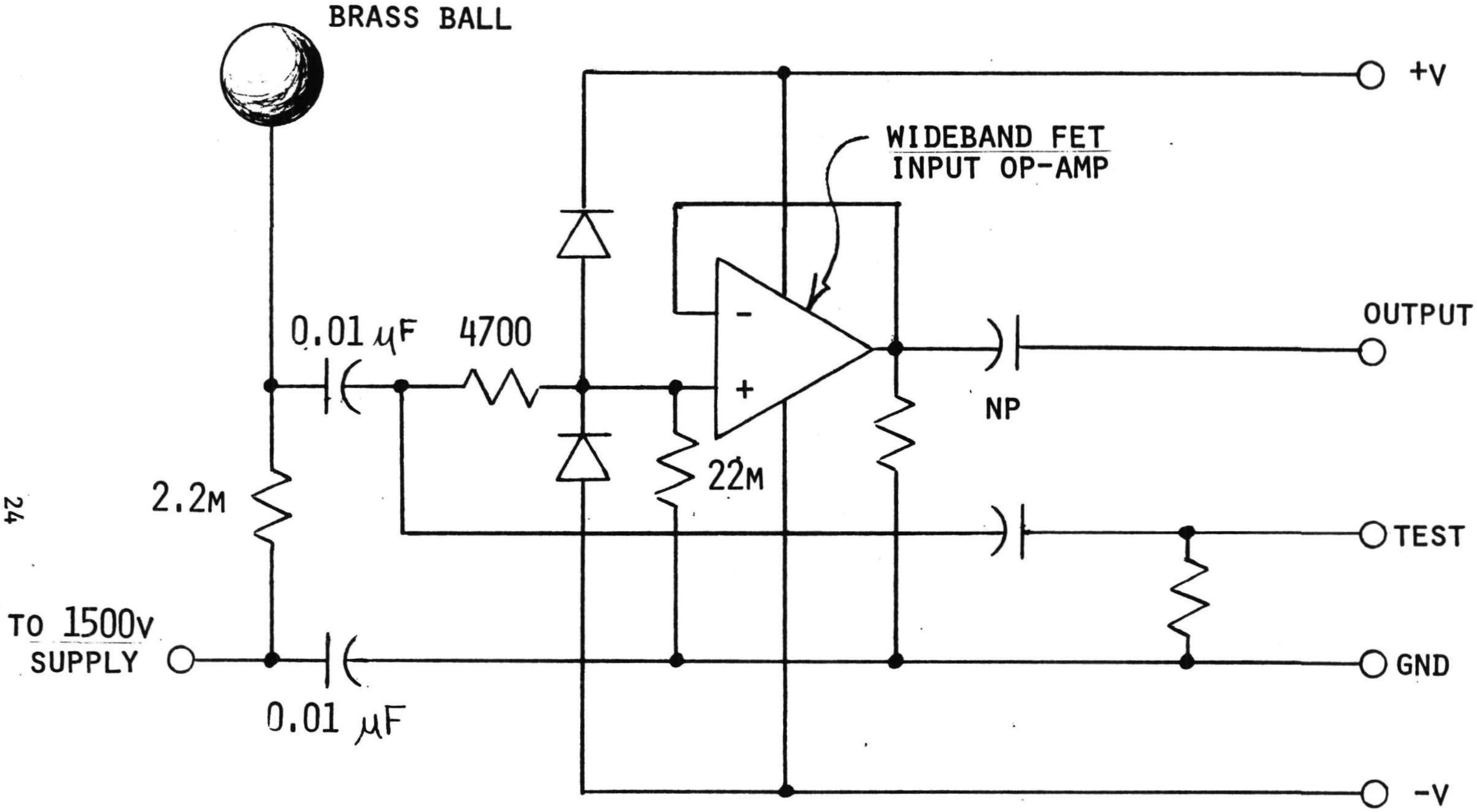


Figure 14 Charge Preamplifier Schematic

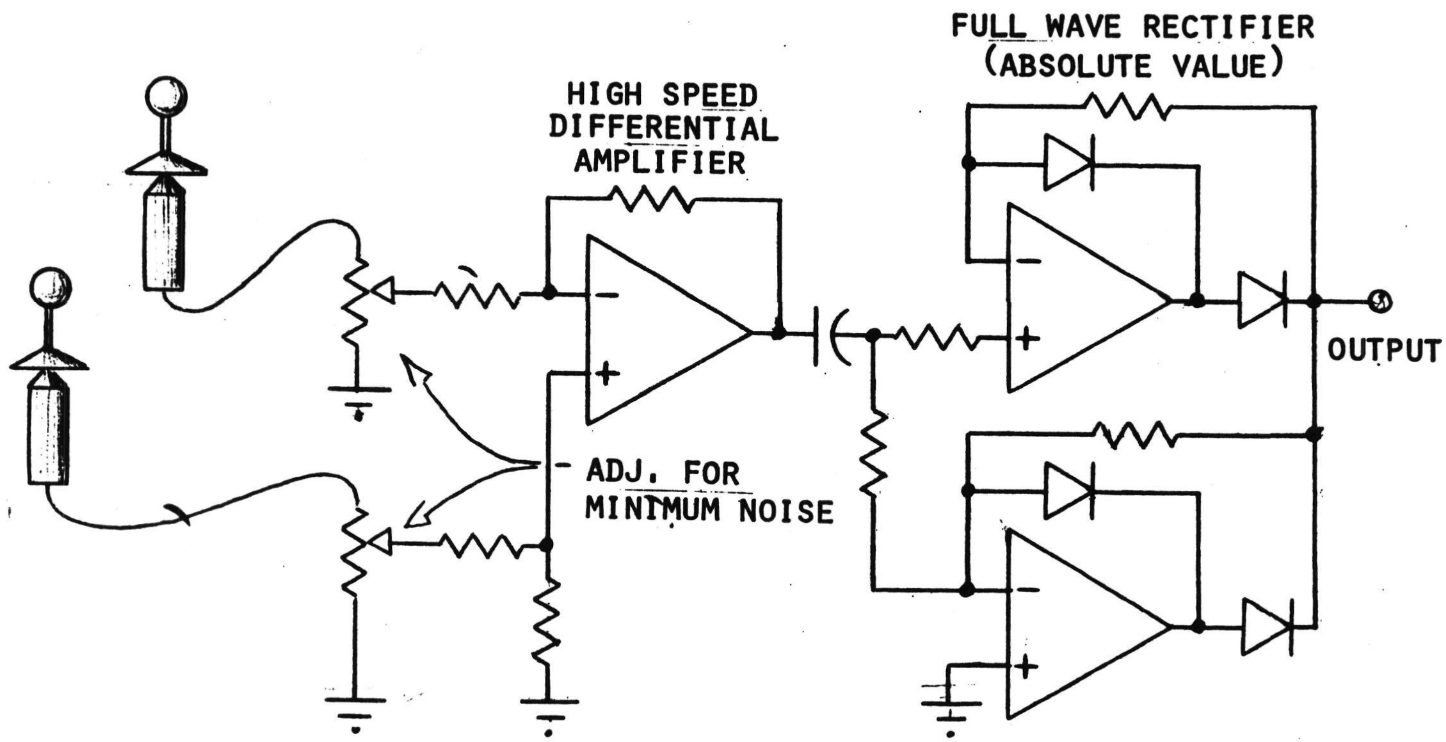


FIGURE 15 MULTI-BALL DIFFERENTIAL AMPLIFIER SETUP

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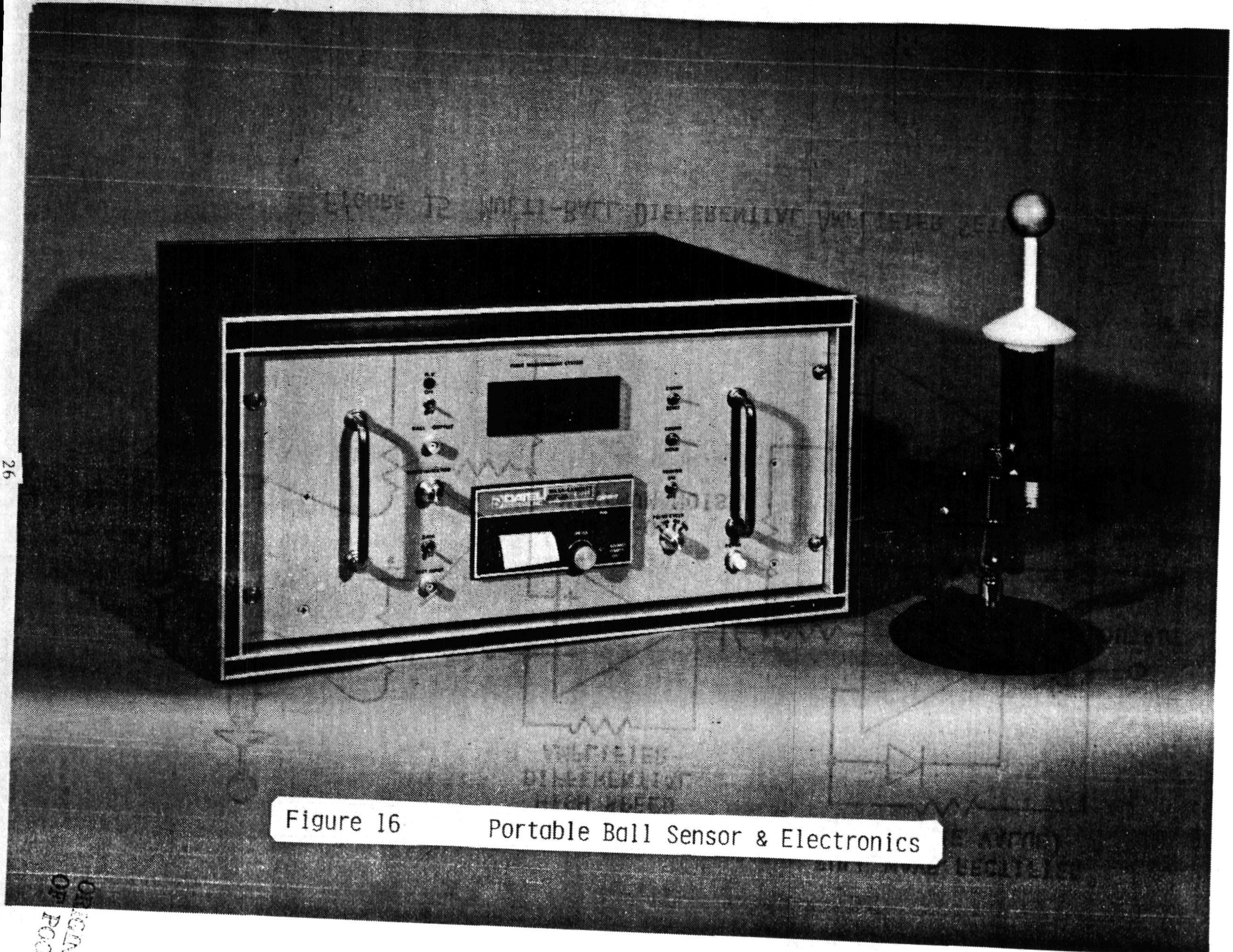

Figure 16 Portable Ball Sensor & Electronics

subsequent hits. Total accumulation is displayed on the counter while the printer can be set to record counts during 1, 10, 50 and 100 second intervals, thus providing a time history. This unit was used in several burn tests where movement of facility equipment became impractical. It was packaged in the single unit shown in figure 17.

Wire Detector: A variation of the ball sensor replaces the ball with a 5-inch length of bare wire extended horizontally for free-falling fiber counting (ref. 7). The decreased effective capacitance due to the reduction in area of the sensor increases the relative charge transfer between the fiber and wire. This increases the sensitivity by a factor of about 35 for fibers in the 1 to 3 millimeter range. The increased output enhances the signal to noise ratio to more acceptable levels at these difficult lengths.

It is felt that further development of the wire sensor could provide a very useful measurement tool for fiber counting at lengths below 3 millimeter.

Further improvements: More recent testing at low fiber lengths with both the ball and the wire has uncovered several potential areas for improvement in noise reduction. Experiments using a discrete component FET input amplifier indicate that certain low-level noise characteristics of the operational amplifier can be avoided in a carefully designed unit. Also, the incorporation of a gain stage within the case containing the preamp below the sensor, can avoid some externally introduced noise in the system. The MCA, for instance, has a lower limit noise level that could be avoided by an increase in sensor output level. Care must be exercised in the design, however, to maintain the fast rise times necessary for length-linearity over the range of interest.

Destructive Discharge Detectors.- This class of fiber detectors can range from a simple alarm device to a counter and if properly designed and implemented can also make some determination of length.

Fiber Alarm/Counter: A simple alarm device was designed which also served to quantify the level of contamination in the chamber instrumentation area (fig. 18). The design used a 700-volt d.c. supply with an 8 microfarad capacitor, for energy storage, connected to a simple grid of parallel conductors. Constructed of number 20 wire spaced on about 3 millimeter centers it had an area of about 0.1 square meter. Air intake was fan forced with a filter attached to the exhaust. An alarm with a digital counter served to estimate the level of contamination. Fibers, drawn in by the air stream, coming in contact with the charged grid would initiate an arc of sufficient energy to eliminate the fiber as an electrical hazard. A shunt connected in series with the grid sensed these discharges and incremented the digital counting circuit. Resets were provided for the counter and the alarm. Residue which might somehow escape destruction was hopefully captured by the exhaust filter. To accomplish the destruction or reduction of the contamination, the device was run continuously during periods of activity in the test area. It was mounted over the anteroom entry door in the instrumentation area.

The device was evaluated in several burn tests for use as a field test instrument. It yielded, however, to the more versatile Schrader Grid.

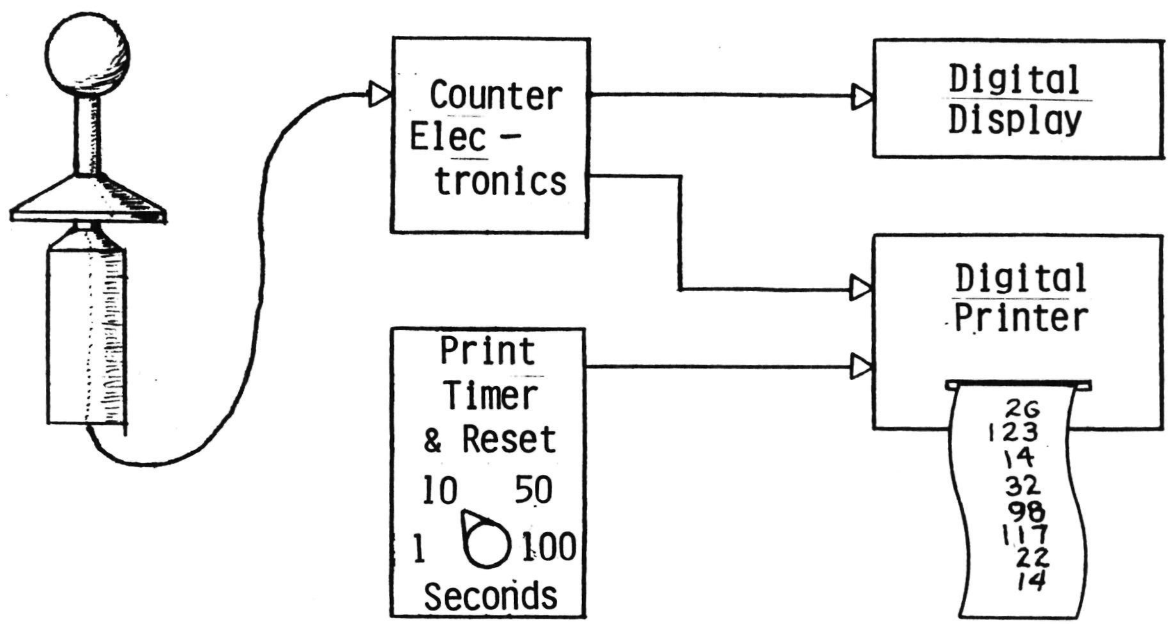


FIGURE 17 PORTABLE BALL SCHEMATIC

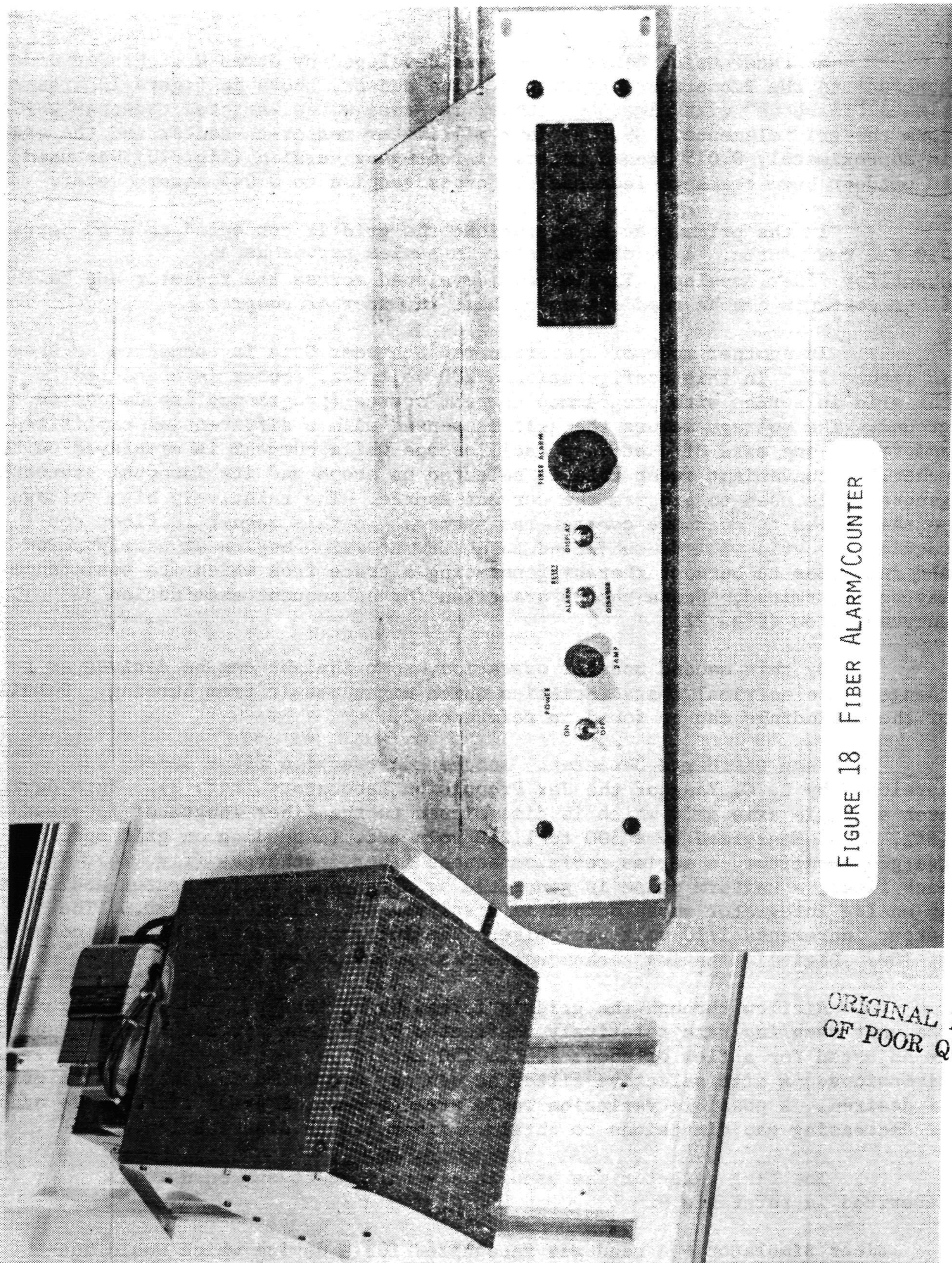


FIGURE 18 FIBER ALARM/COUNTER

Schrader Grid: This device was developed by James H. Schrader under contract to the Bionetics Corporation. The sensor, shown in figure 19, resembles a "fishbone" with alternate number 18 steel wires strapped together to form the grid elements. Spacing is 2 millimeter center-to-center and the area is approximately 0.015 square meter. A four-gang version (fig. 20) was used in outdoor burn tests to increase the cross section to 0.044 square meter.

In the prime mode of operation, the grid is connected to a 60 hertz 250 Vac rms source. A 10 ohm resistor in series serves as a shunt for fiber sensing. The voltage developed across the resistor due to fiber contacts can be read out on a chart recorder or counter.

In another mode of operation the Schrader Grid is connected as shown in figure 21. In this configuration a 200 volt d.c. source is connected to the grid in series with programmed current source (programmed impedance) to ground. The voltage across the grid is sensed with a differential amplifier and fed to one axis of a storage oscilloscope while current is displayed on the other. A convenient sweep rate is selected on scope and its internal sawtooth generator is used to program the current source. The relatively high voltage source serves to overcome contact resistance. In this manner, a fiber contacting the grid will be subjected to a current which begins at nearly zero and increases to burnout thereby generating a trace from which its resistance may be determined. Scope photos are taken for subsequent examination and documentation (fig. 22).

By this second mode of operation, some insight can be derived as to changes in electrical characteristics which might result from burning. Details of these findings can be found in reference 2.

Yang Discharge Detector: Another destructive fiber sensor was developed by L. C. Yang of the Jet Propulsion Laboratory (ref. 8). This device uses a single axis grid which is dimensioned to the fiber length of interest (fig. 23). Energized by a 500 to 1,200 volt d.c. (depending on grid spacing) charged capacitor, a series resistor senses fiber discharges (fig. 24). For each fiber, a uniform pulse is generated by a one-shot multivibrator and fed to an analog integrator whose output is displayed on a chart recorder. The output increments 1/10 volt per pulse. The integrator resets for each count of 100. Digital counting techniques can also be employed.

Airflow through the grid is forced by an integral fan which makes the unit sampling rate relatively unaffected by ambient air motion. Fan speed is adjusted for a flow of about 100 to 150 meters per minute depending on grid dimensions. A size selective filter screen may be placed in front of the grid if desired. A possible variation would arrange several grids cascaded in order of decreasing gap dimensions to obtain a fiber length distribution.

The Yang detector was used in several end-to-end burn tests described in reference 9.

Fiber Simulator.- A need was recognized for a device which would nondestructively simulate the burnout characteristics of carbon fibers. Such a device could be used to test circuits and equipment in a selective manner

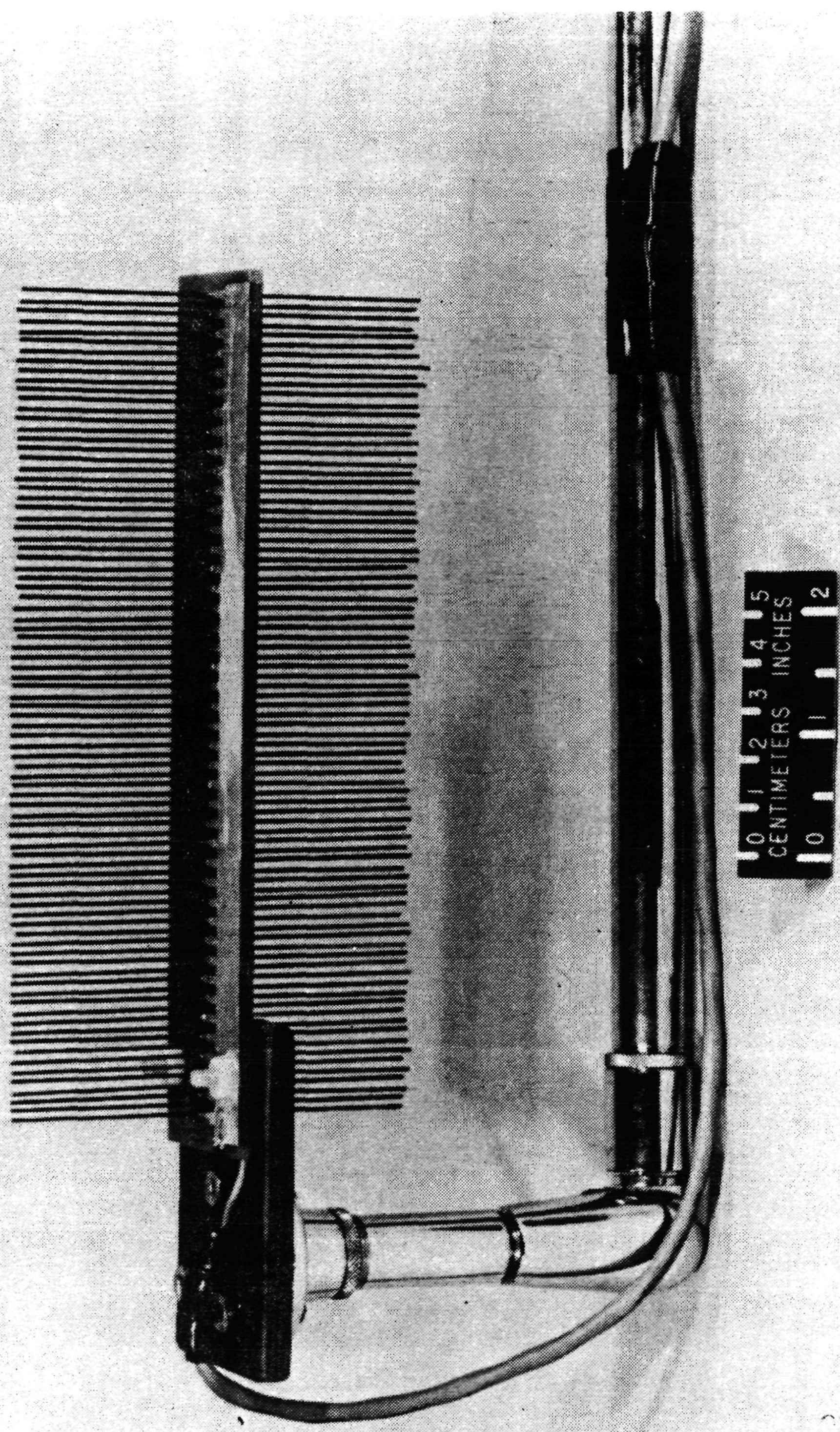


Figure 19 Schrader Grid

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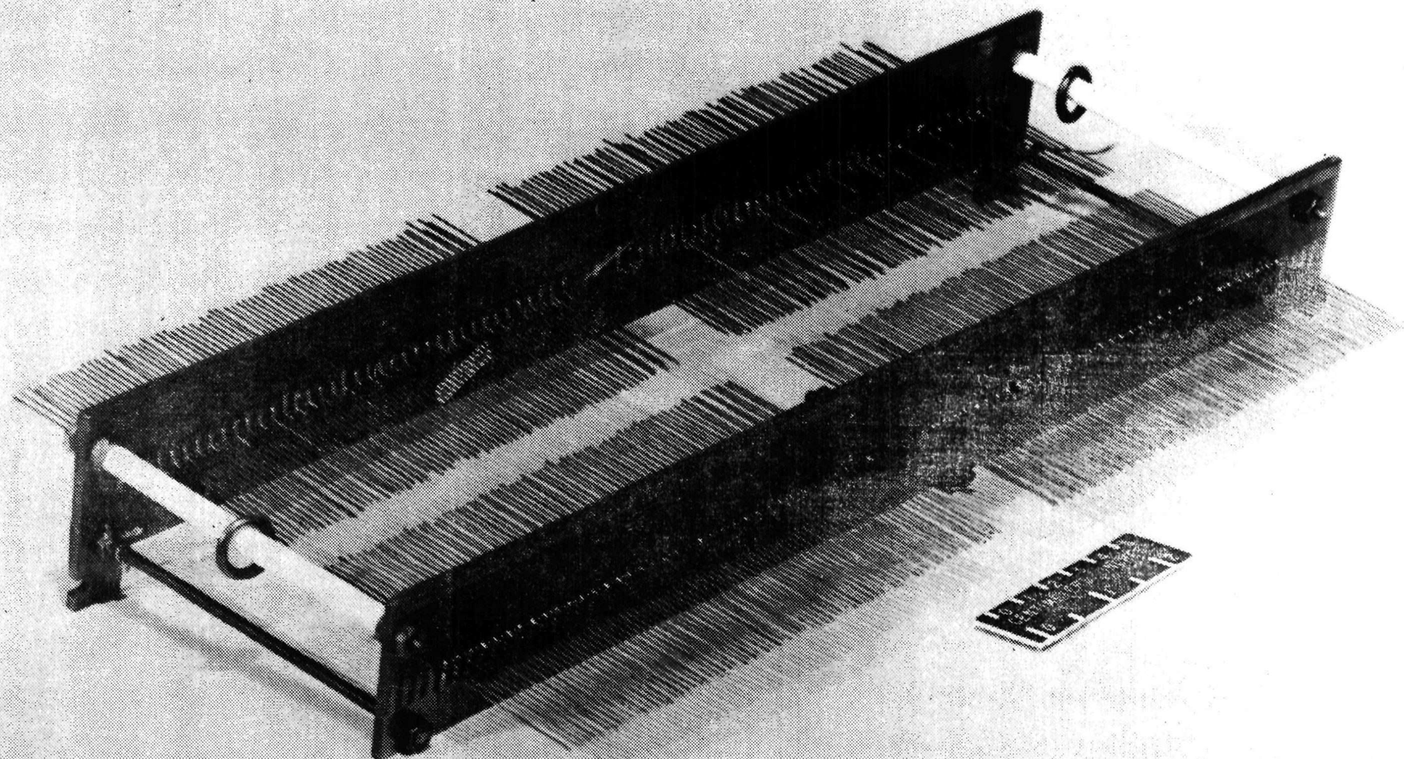


Figure 20 Schrader Grid-4 gang

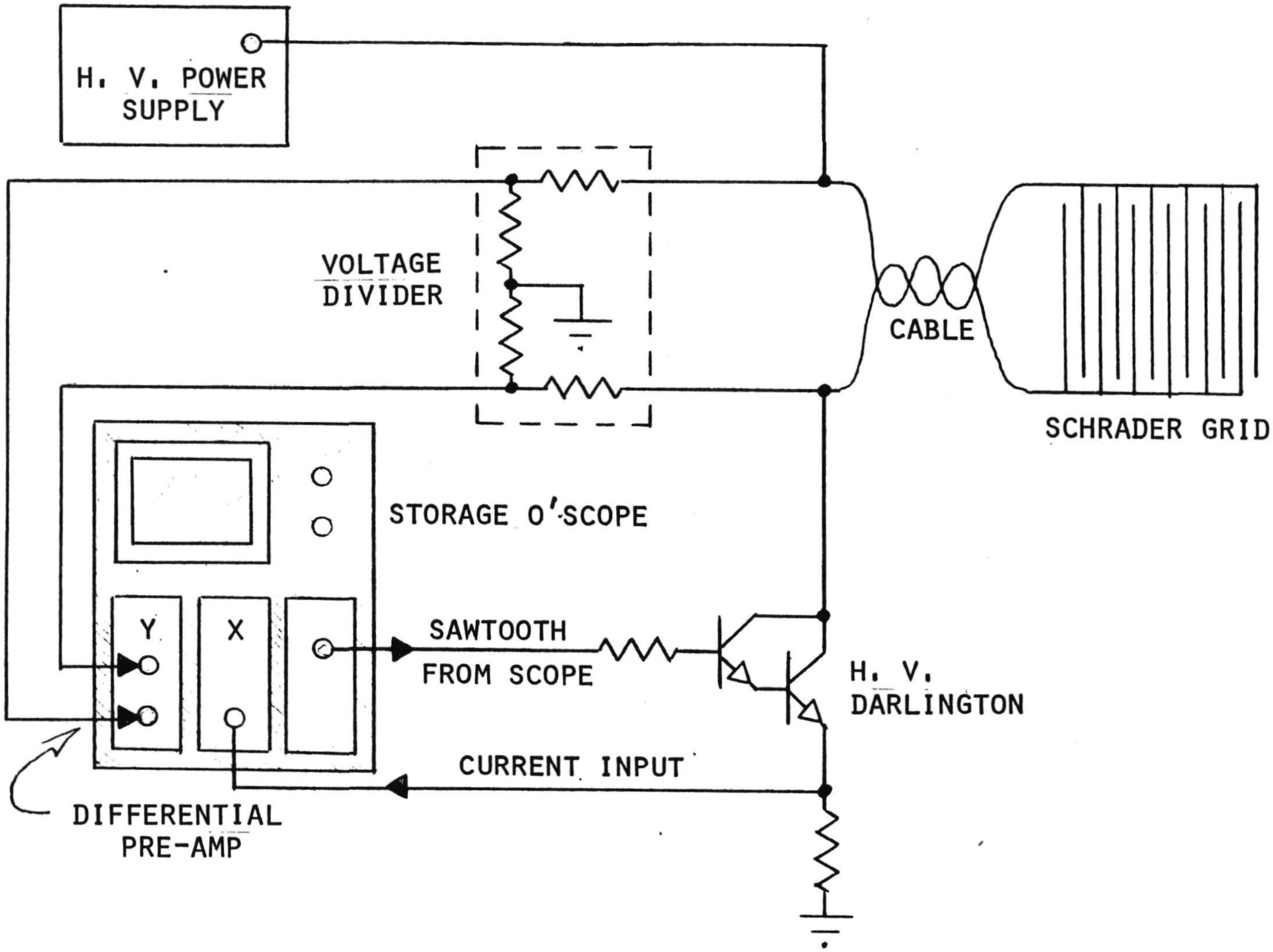
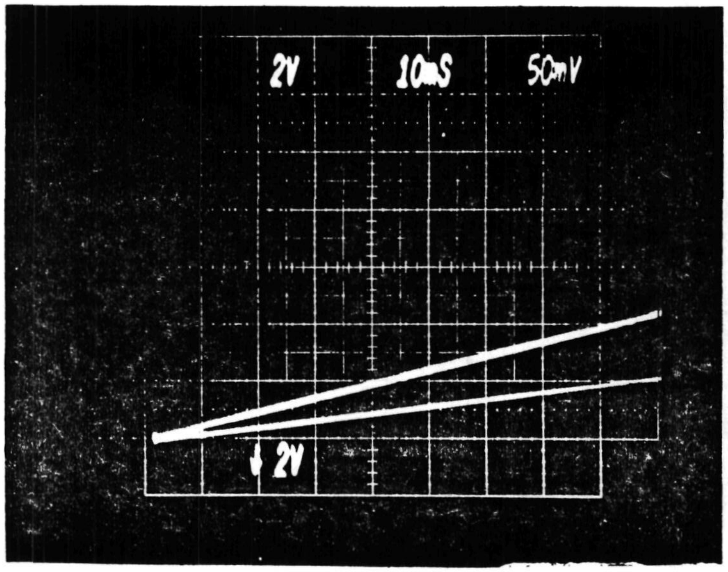
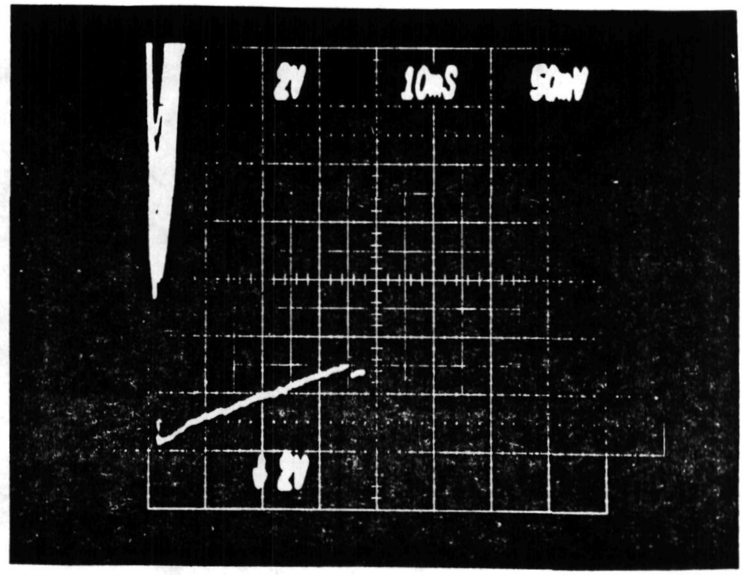



FIGURE 21 SCHRADER GRID SCHEMATIC, ALTERNATE MODE

VOLTAGE 20v/div.




Current, 5 ma/div.

CALIBRATION RESISTORS
500, 1000 ohms

FIRE-RELEASED FIBER

Figure 22 Schrader Grid Scope Photos

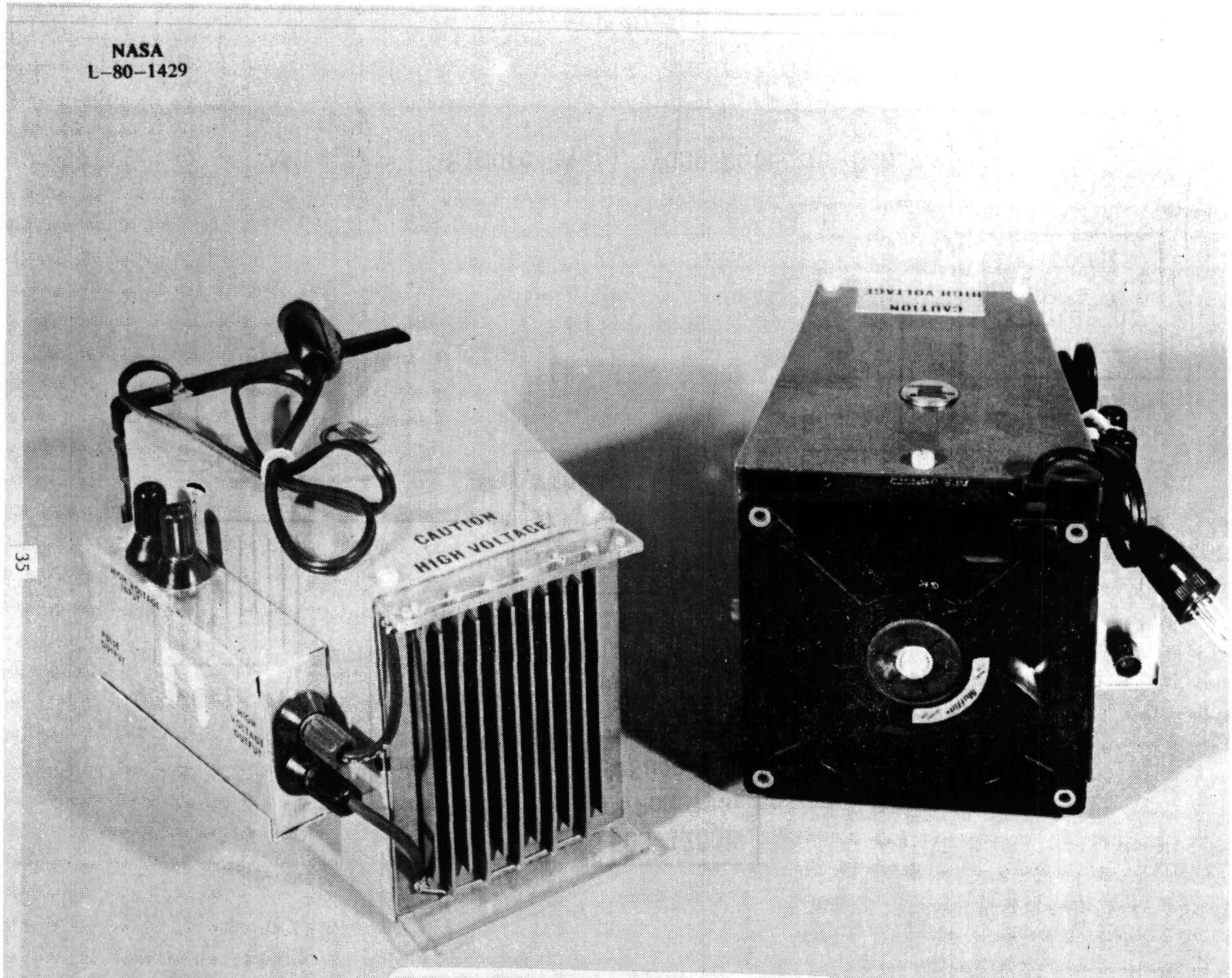



Figure 23 YANG DISCHARGE DETECTOR

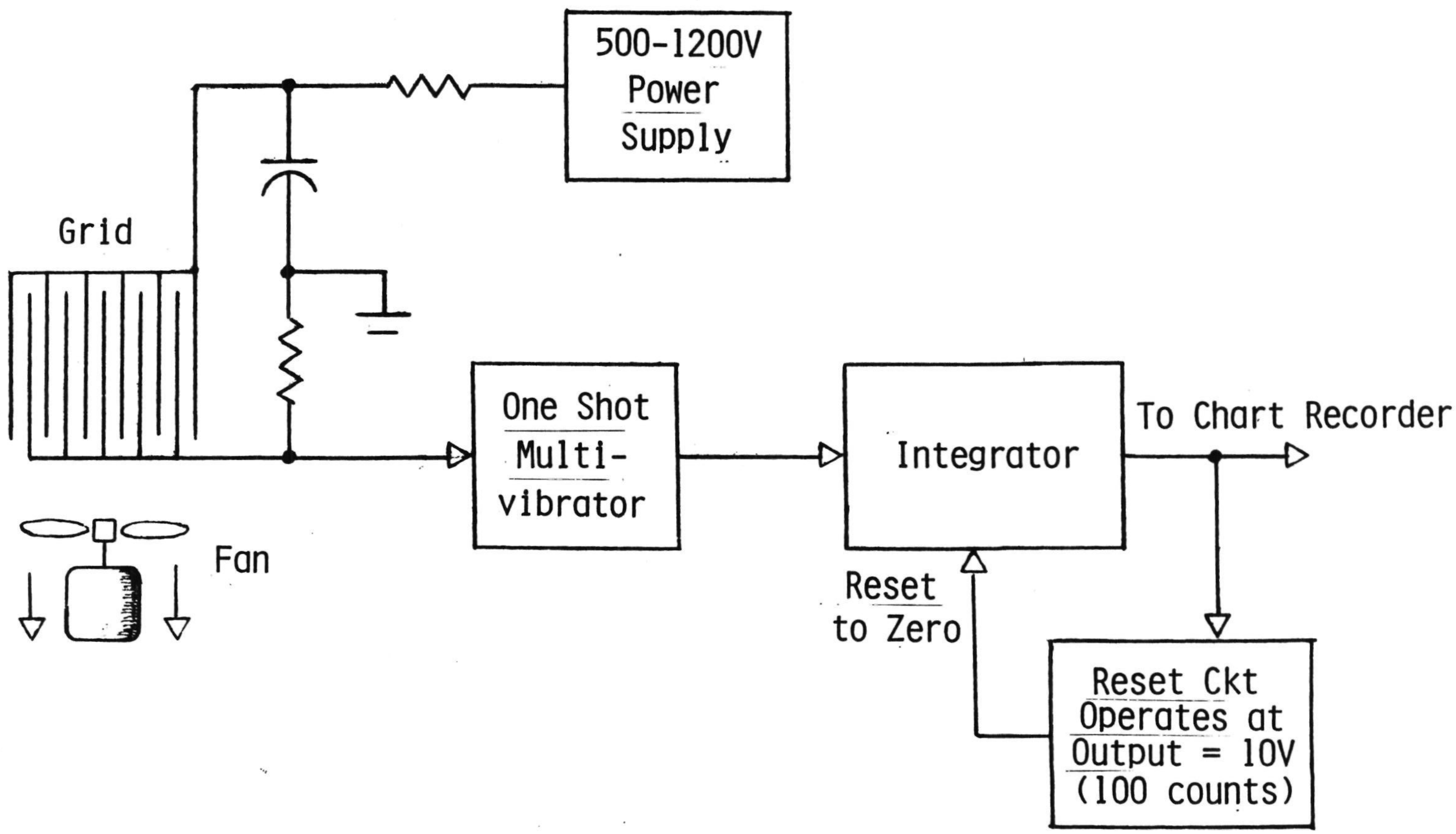



Figure 24 Yang Detector Schematic

allowing a methodical and detailed analysis of this type of fiber induced failure. Functional requirements are as follows:

1. Operate for all voltages of interest, namely 0 to 230 Vac rms or $\pm$350 Vdc.

2. Simulate a range of resistances selectable to a suitable value (i.e., contact spacing would determine the resistance selected).

3. Simulate the burnout dynamics by approximating the time necessary to dissipate about 100 millijoules for the voltage applied.

4. Provide visual and audible alarms if burnout levels are exceeded.

A circuit was designed fulfilling these requirements and is shown, in simplified form, in figure 25. It consists of a resistance selector switch, a current sensing absolute value circuit, a delay circuit, a comparator and relay.

A resistance is selected which approximates that represented by a length of a given fiber necessary to bridge the contact points under question. A six millimeter length of T-300 is about 3,000 ohms, for example. When the probes contact the circuit in question a current is sensed, proportionately converted to a voltage, rectified and applied to the RC circuit. When and if C charges to the voltage for which the comparator is set, the relay is actuated opening the test circuit and sounding the alarm. Calibration is made for the particular fiber in question (i.e., for T-300 we would use about 15 mA).

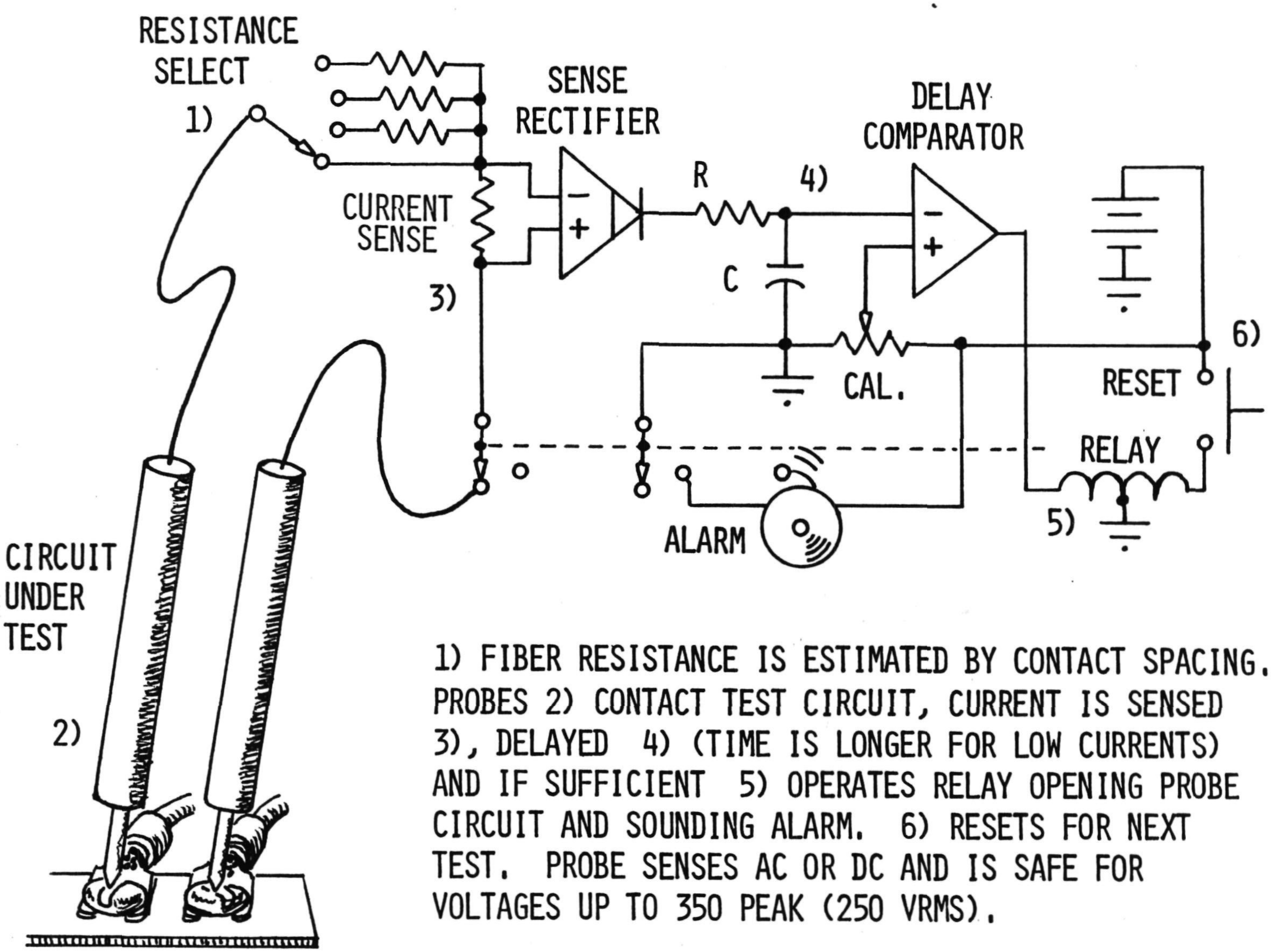
The battery powered device is packaged in a small hand held plastic case, as shown in figure 26 and equipped with standard meter leads.

It should be noted that since the simulator probe isolates the circuit "break" phenomena to enclosed relay contacts, any arc characteristics of a fiber induced short are ignored by this test method (arcing will not occur at the probe site but at the relay in the box). Tests using the probe were therefore used only for voltages below which sustained arcs might be expected, i.e., 230 Vac and below.

## TARGET INSTRUMENTATION

A testing arrangement which would include all instruments necessary to monitor all test subjects, or targets, was considered impractical. Fixed instrumentation was therefore kept as simple and functional as possible. Elements common to most tests such as temperature, humidity, test time, power voltage and current were included. Portable and special test equipment was obtained from other divisions at the center or rented as needed.

A 60-channel event recorder was wired through a patch panel where connections to chamber wiring could be selected using special interface circuits (also wired through the patch panel). Figure 27 shows the instrumentation room and a block diagram is shown in figure 28. Digital voltmeters,




1) FIBER RESISTANCE IS ESTIMATED BY CONTACT SPACING. PROBES 2) CONTACT TEST CIRCUIT, CURRENT IS SENSED 3), DELAYED 4) (TIME IS LONGER FOR LOW CURRENTS) AND IF SUFFICIENT 5) OPERATES RELAY OPENING PROBE CIRCUIT AND SOUNDING ALARM. 6) RESETS FOR NEXT TEST. PROBE SENSES AC OR DC AND IS SAFE FOR VOLTAGES UP TO 350 PEAK (250 VRMS).

Figure 25 Fiber Simulator Probe Schematic

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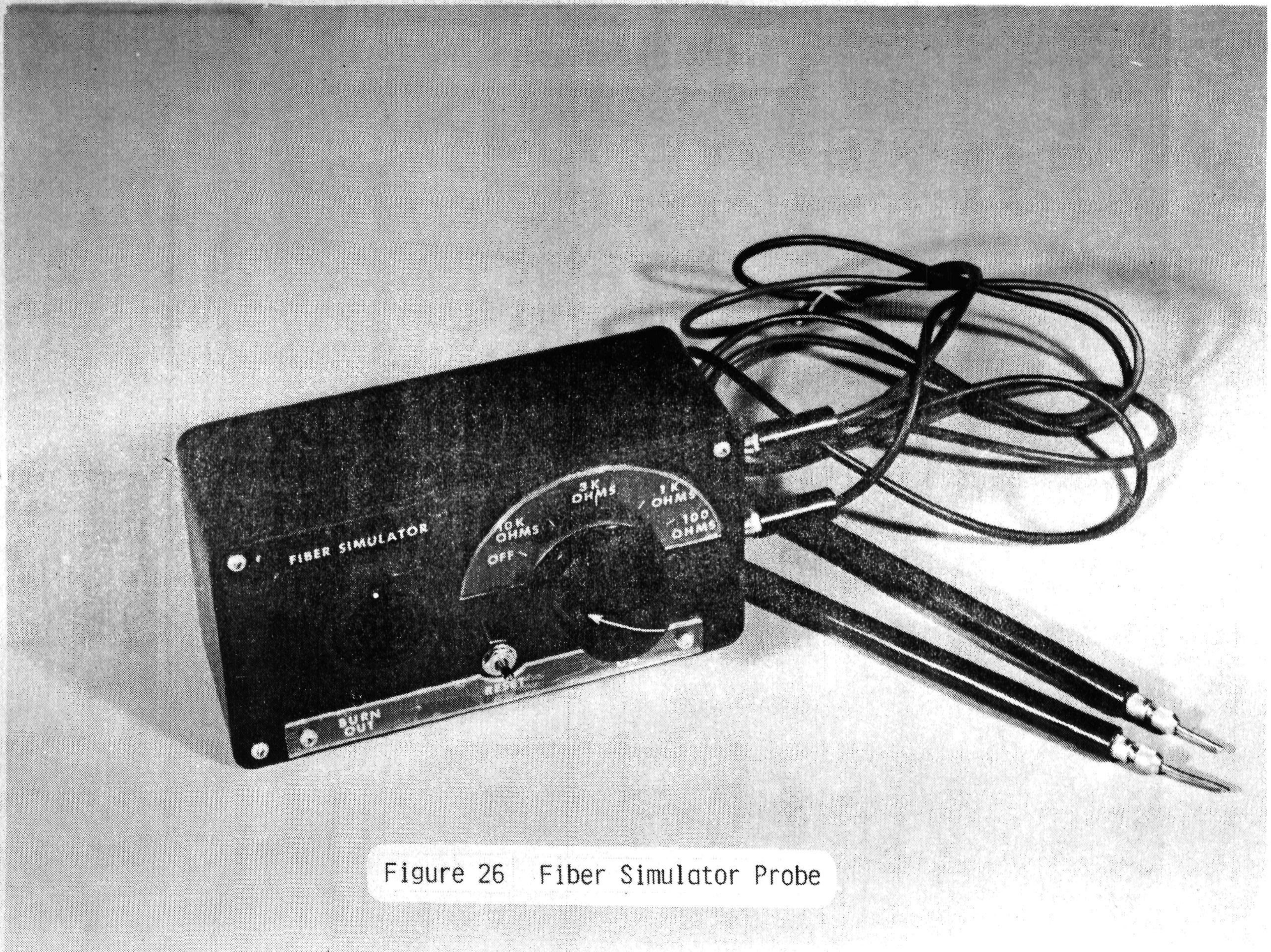


Figure 26 Fiber Simulator Probe

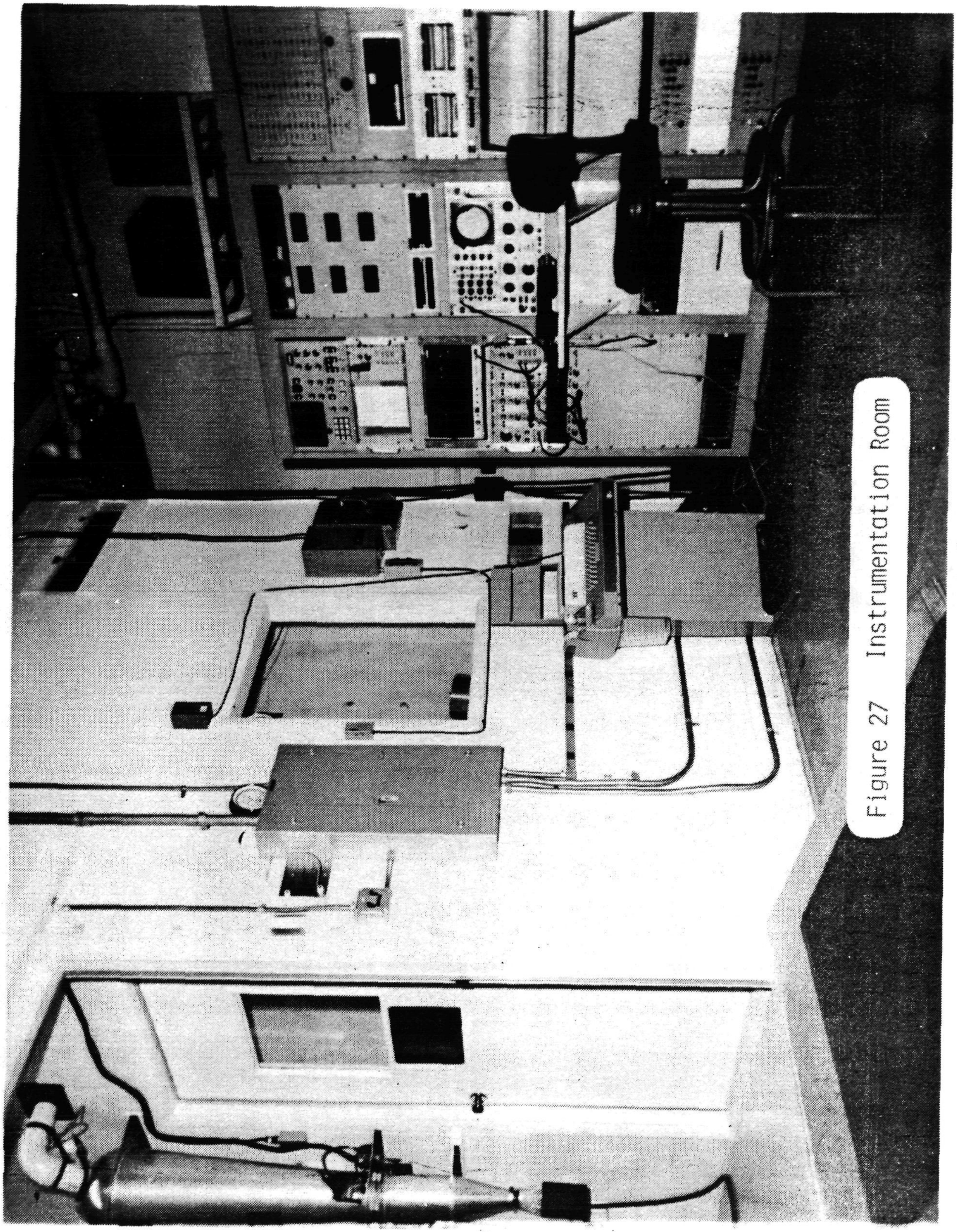

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Figure 27 Instrumentation Room

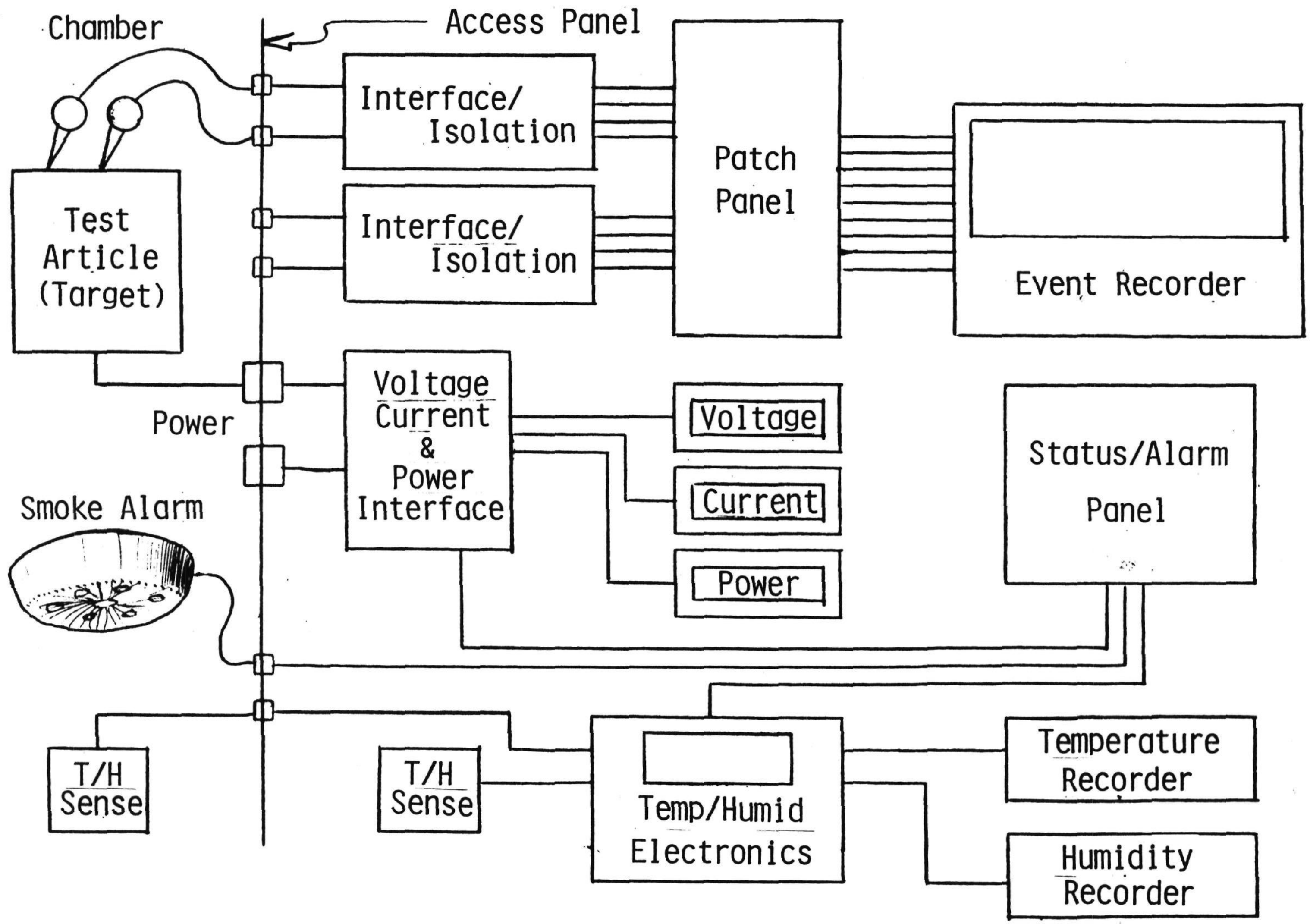


Figure 28 Target Instrumentation Block Diagram

voltage and current monitors as well as an alarm/status panel were provided. Temperature and humidity could be read or monitored using separate recorders throughout the test.

## VULNERABILITY TESTING

The vulnerability test procedure for electrical and electronic targets varied considerably from item to item. Although not rigorously followed in every case the steps identified in figure 29 were considered in test planning.

The ventilation analysis is a gross electrical and mechanical review of the circuit and its enclosure to determine the maximum fiber length likely to be admitted. In general a circuit with more than about 50 nodes will consume more time and effort in analysis than to expose the device. The vulnerability of simple devices can frequently be determined by circuit analysis. Questionable or more complex devices were probed. Minimum fiber length vulnerability was estimated by examining the minimum distances between exposed conductors.

Maximum and minimum length estimates were then used to determine at what lengths fibers were to be chopped for exposure testing. After connecting suitable instrumentation to detect failure, the device was placed in the chamber and testing begun.

Controlling contamination was one of the more difficult tasks in fiber exposure testing. To minimize those difficulties testing usually began at the shorter lengths proceeding to the longer ones. This sometimes eliminated the need for chamber cleanup when testing revealed low vulnerability. In these instances only the test target needed to be cleaned before proceeding to the next length, since redissemination (the stirring up of previously settled fibers) of smaller fibers is less likely to affect a failure. This was not always possible, however, since a number of runs (about 4 to 6 at each length) must frequently be made to gather good statistical data. Some articles may have been exposed for periods with power switched OFF (but still connected to power) as well as ON. This was done when evaluating user shock hazards for instance. Test interruptions for movement of portable appliances were also made as well as the introduction of fan generated turbulent airflow to simulate more realistic conditions.

If a concentration level of $10^4$ fibers per cubic meter is maintained in the chamber and exposure reaches $10^8$ fiber-seconds per cubic meter with no failure, the test will run for nearly 3 hours (a device tested to $E = 10^8$ fiber-seconds per cubic meter is for practical purposes considered invulnerable). As can be seen this can be a time-consuming process and a very careful selection of test articles was made to avoid needless or redundant operations.

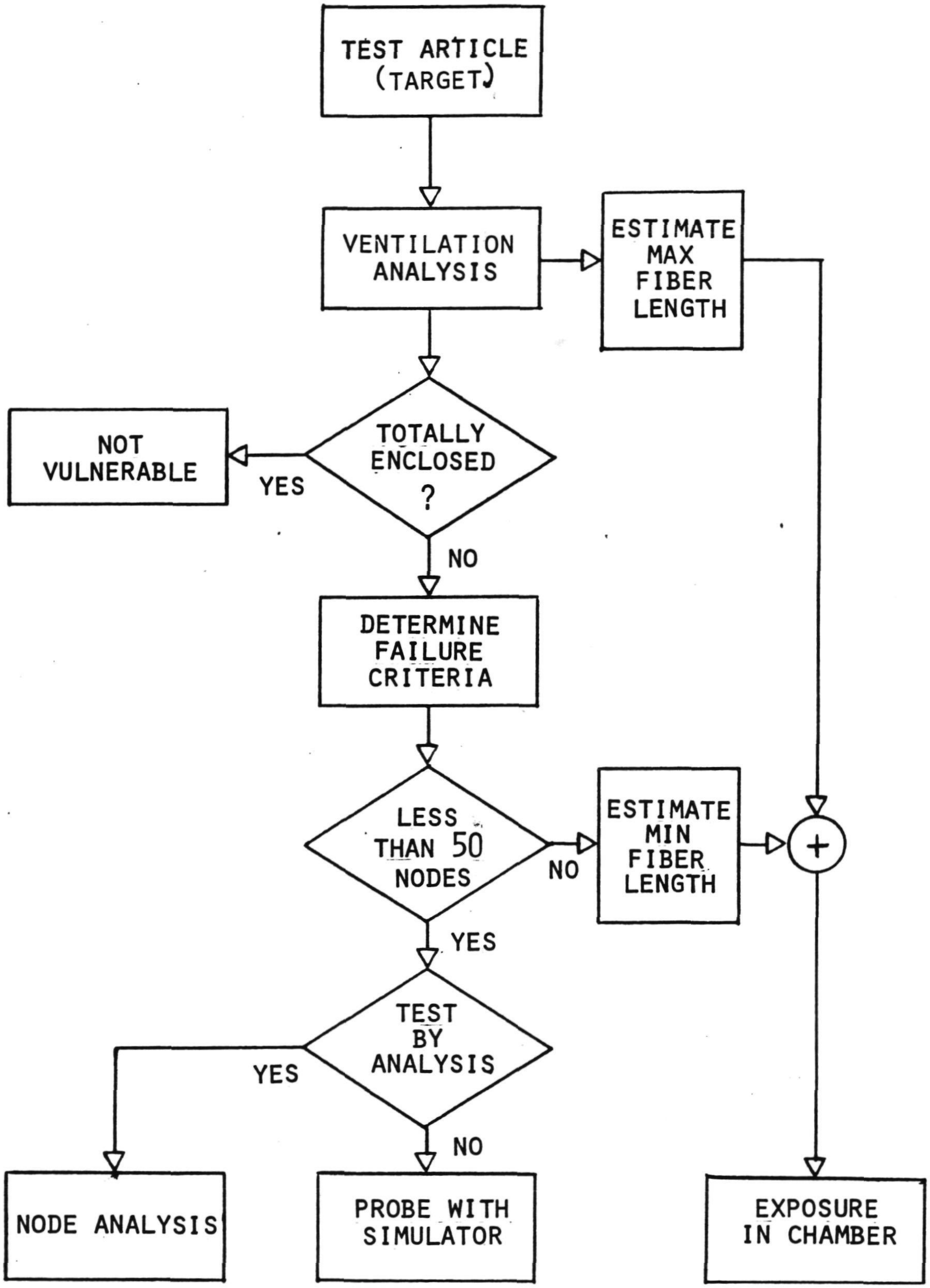


Figure 29 Vulnerability Test Procedure

## CONCLUSIONS

The design objectives for a Carbon Fiber Exposure Facility have been met and are summarized as follows:

1. Carbon fibers be chopped such that 90 percent are within about 5 percent of the length selected and were aspirated in still air giving uniform deposition, within a factor of 2, over the test area.

2. Instrumentation was developed or improved which could determine and record levels of concentration and exposure, of the aspirated fibers, in around the test target for the duration of the test or until a desired exposure was reached.

3. The facility provided fixed instrumentation for the measurement of temperature, humidity, time and power as well as access facilities for special purpose test equipment, as needed.

In addition to the facility developments, the following instrumentation was developed for field operations:

1. A fiber simulator probe with which simple electrical and electronic circuits could be tested for failure resulting from specified fiber contacts without actual exposure.

2. The Schrader Grid used in field burn tests to count fibers as well as evaluate resistance and burnout characteristics.

3. The Yang Detector to count specified lengths of fibers during field burn tests.

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16. Abstract


A facility has been constructed to evaluate the risk associated with the exposure of electrical and electronic equipment to airborne carbon/graphite fibers. A wide variety of instrumentation adapted or developed for the program is described and illustrated.


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